

A REGIONAL APPROACH TO HIGHWAY SOILS  
CONSIDERATIONS IN INDIANA

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BY

W. J. SISILIANO

# JHRP

JOINT HIGHWAY RESEARCH PROJECT  
PURDUE UNIVERSITY AND  
INDIANA STATE HIGHWAY COMMISSION

Informational Report

A REGIONAL APPROACH TO HIGHWAY SOILS  
CONSIDERATIONS IN INDIANA

TO: J. F. McLaughlin, Director  
Joint Highway Research Project

September 15, 1970

FROM: H. L. Michael, Associate Director  
Joint Highway Research Project

File No.: 6-1

The attached research report "A Regional Approach to Highway Soils Considerations in Indiana" is presented to the Board as information. The research reported was not conducted with Project financing but was conducted by Mr. Sisiliano with the cooperation and interest of the Materials and Test Division of the ISHC where Mr. Sisiliano was and is employed. Mr. Sisiliano also used the research for his MSCE degree awarded by Purdue University in August 1970. The topic of the research is one in which much Project research has occurred and in which the ISHC has exhibited continued interest.

The report is presented to the Board for the information of its members and to obtain broader distribution of the results of the research.

Respectfully submitted,

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by

William J. Sisiliano

Joint Highway Research Project

File: 6-1

Purdue University  
Lafayette, Indiana  
September 15, 1970

REPORT

REPORT OF THE COMMISSIONER OF THE  
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## ABSTRACT

Sisiliano, William J., M.S.C.E., Purdue University, August 1970.  
A Regional Approach to Highway Soils Considerations in Indiana.  
Major Professor: Dr. C. W. Lovell, Jr.

It is hypothesized that a Regional or Physiographic Sub-Division Approach can be effectively used in preliminary studies and investigations generally to predict the environment and to formulate the major soils problems to be considered in the design of a modern highway facility. This is intuitively obvious to practicing soils engineers, although they may not think of it in exactly these terms. Each practicing soils engineer tends to develop his own personal filing system of engineering experiences, usually based on geographic location, rather than physiographic unit.

Many factors are of influence in a study of this nature. Those which appear to be most significant are the geologic origin and complexity of the soil parent materials, the topography, and the general texture of the soils. If the influence of these factors can be quantified within a physiographic region, the anticipated soils problems and their general magnitudes can be predicted for a project in that region.

Approaches to the generalized and specific quantification of significant factors influencing a Regional Approach to Highway Soils Considerations have been proposed. Available data from related disciplines, such as physiography, geology, pedology, air-photo interpretation and

engineering soils were used in the general approach. Data were compiled from completed Indiana State Highway Commission Projects and Roadway Soil Surveys performed by Consultants, and statistical methods were applied to some of these data in the specific approach. Table 14, entitled "Ratings of Highway Soils Considerations for Landforms within Physiographic Regions of Indiana" probably contains the most useful information resulting from this study, particularly for soils engineers inexperienced in this geographic location. It reflects eleven years of personal experience in soil mechanics and foundation engineering and also the judgments of associates with longer periods of practical experience.

The general relationship between the present Indiana State Highway Commission's standards, policies and procedures as related to Soil Mechanics and Foundation Engineering and a Regional Approach to Highway Soils Considerations in Indiana has been studied. Suggestions for incorporating the Regional Approach in the present Indiana procedures have been advanced. It is believed that these suggestions have definite potential for effecting net economy.

It is concluded that the Physiographic Sub-Division Approach is capable of contributing significantly and economically in the preliminary stages of planning, route location and design of modern highway facilities in the State of Indiana. To optimize the approach, a further subdivision of the Physiographic Units shown on Figure 1 is probably required. The landforms or Engineering Soil Parent Material Areas shown on Figure 9 seem to provide areas of sufficient homogeneity.

Within such areas the classes and severity ratings of highway soils problems can probably be generalized with confidence. This was accomplished for the Calumet Lacustrine Plain, a subsection of the Northern

Lake and Moraine Region. It is felt that the same procedure can be applied to the other physiographic units to provide similar information of practical value to the Indiana State Highway Commission.

The conclusions reached in this study represent the personal views of the writer based on his experience, and they should not be taken necessarily to represent the views of other personnel of the Indiana State Highway Commission.

## INTRODUCTION

Among the factors to be considered in the planning, location, design and construction of modern highway facilities are the soil and rock conditions within the corridor of the proposed route. These conditions are inherently complex and will need to be studied in detail before certain design and construction decisions are reached. However, there is considerable logic in deriving a generalized description of them prior to assessing details. This can be accomplished by examination of the factors of origin, parent material topographic expression and climatic environment. If the engineer has job experience where these general factors were similar, even though geographically removed from the route under study, he has a valid basis for the transfer of past experience. In other words, he can anticipate the likely challenges of the new project. A recognition of these interrelations and a concise recording of them would allow even an inexperienced engineer to exercise valuable insight. All of this occurs at the preliminary stage of investigation and is intended to enhance the interpretation of detailed physical studies, as opposed to displacing them.

The contents of this investigation reflects the writer's eleven years of experience in soil mechanics and foundation engineering (nine years related to highways), and therein lies the incentive for the author's research into the subject. Also reflected in this study are relevant experiences and judgments of some associates with longer years of experience.

As suggested above, the descriptors which appear most significant in a generalized assessment of route conditions are the geologic origin and complexity of the parent materials, the topographic expression and the general texture of the soils, particularly clay content. The topographic expression is conveniently characterized by the branch of geology known as physiography or regional geomorphology, which defines units of unique landform combinations based upon factors of structure, process and stage. Therein lies the basis for the Regional or Physiographic Sub-Division Approach. The physiographic units of Indiana adopted for this study are those defined by Wayne (72)<sup>1</sup> as shown in Figure 1. A further subdivision to the landform or Engineering Soil Parent Material Area level is needed to characterize the geologic origin and complexity of the soil parent materials, and to afford a measure of the soil distribution throughout the physiographic region. Figure 9 and References 1 and 73 were used for this purpose. The general texture of the soils is described by various soil index properties, which must be determined by physical tests.

To be of practical consequence, the findings and conclusions of this study must be interpreted in terms of the present standards, policies and procedures concerning Roadway Soil Surveys used by the Indiana State Highway Commission. Therefore, the general relationships between the State of Indiana's methods for performing Roadway Soil Surveys and a Regional Approach to Highway Soils Considerations in Indiana have been investigated. Suggestions for incorporation of the Regional Approach into present practice have been advanced. It is believed that if these suggestions were adapted, a net economy would be realized.

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<sup>1</sup>. Numerals in parentheses refer to entries in the Bibliography.



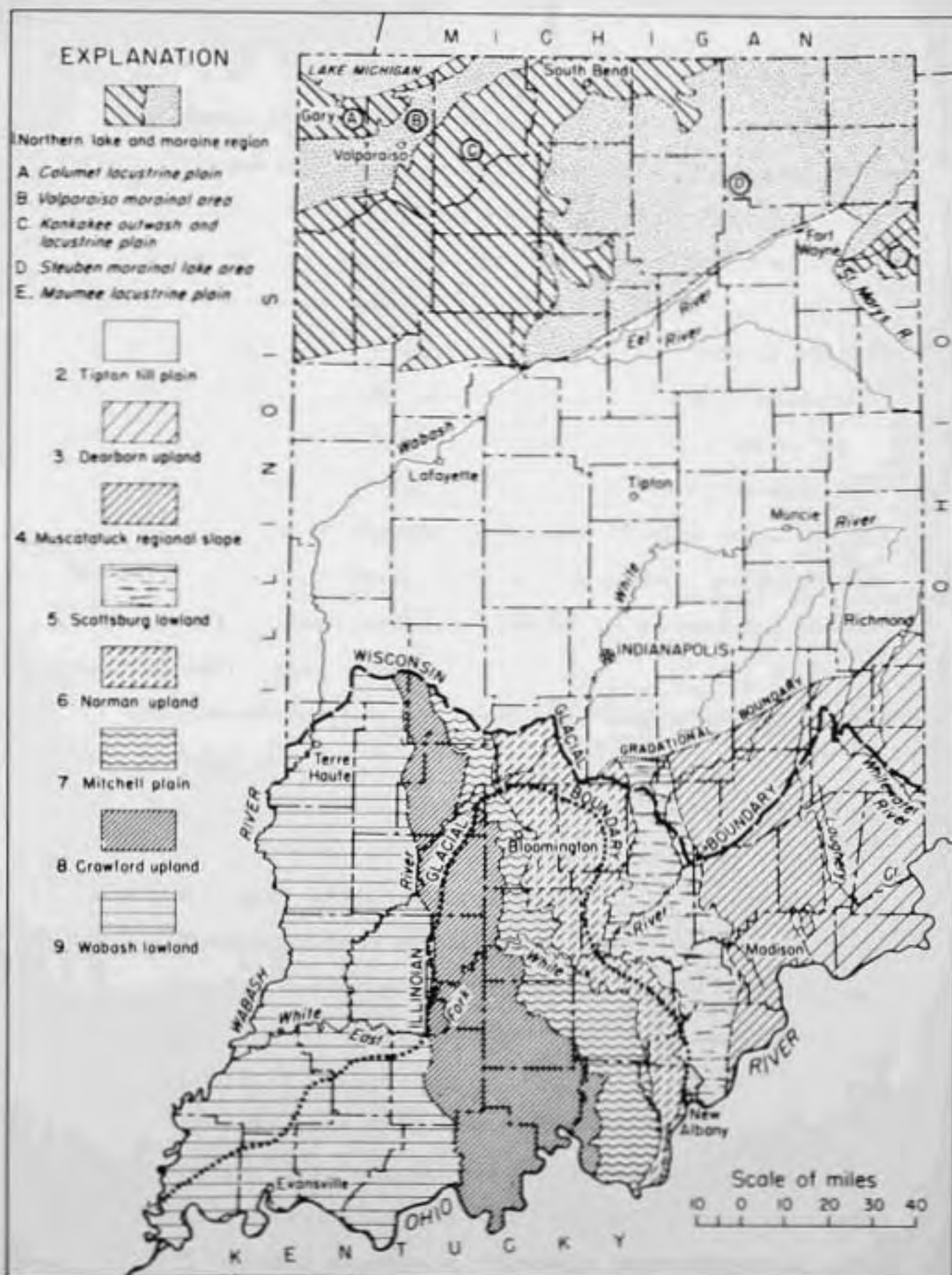


Figure 1 Map of Indiana showing regional physiographic units based on present topography. Modified from Malott (43)



### Purpose and Scope of Study

The purpose of this study is to show that a Regional or Physiographic Sub-Division Approach can be effectively used in preliminary studies and investigations to predict the general soil and rock environment and to provide significant insight into the kinds of problems to be anticipated in the design and construction of a modern highway facility. A further goal is to indicate how the approach can be integrated into the present Indiana State Highway Commission's standards, policies and procedures for performance of Roadway Soil Surveys. In addition to the generalizations possible at the physiographic unit level, variability of soil characteristics was assessed for selected landforms within one unit. The objective was to ascertain the variability of soil conditions within a landform and to frame correlative equations for selected soil characteristics for the landform unit.

The scope of this study involved detailed consideration of the following topics:

Generalized Quantification of Significant Factors Influencing  
a Regional Approach to Highway Soils Considerations.

Methods of Generalized Quantification.

Interpretations of the Generalized Quantification.

Specific Quantification of Significant Factors Influencing a  
Regional Approach to Highway Soils Considerations.

Methods of Specific Quantification.

Interpretations of the Specific Quantification.

General Relationship between Present Indiana State Highway  
Commission Standards, Policies and Procedures as related  
to Soil Mechanics and Foundation Engineering and a

Regional Approach to Highway Soils Considerations in  
Indiana.

That class of soils considerations peculiarly related to pavement design and construction have been omitted from this study due to their specialized nature and the complex and highly relevant soil-structure interaction effects.

## REVIEW OF THE LITERATURE

A literature review has been conducted to generate the necessary background and perspective for highly relevant environmental factors and their interpretation. Included are: climate, physiography, geology, pedology, airphoto interpretation, engineering soils and drainage.

### Climate

The literature shows considerable variation in temperature and precipitation patterns between various locations in Indiana. This is to be expected considering the size of the area involved approximately (36,291 Sq. mi.), the range in latitude (approximately 38° to 42° North) and longitude (approximately 85° to 88° West), and various natural features such as Lake Michigan.

References (6), (13), (40), (52), (57), (65) and (68) describe the climate and weather of the state. Some of the more significant soils problems associated with climate and weather are frost action, erosion, slope instability, failures of piers and abutments, pumping and blowing. The pavement problems are usually minimized by appropriate gradation and thickness of subbase or base courses, and as mentioned previously, are beyond the scope of this study.

Climate does not appear to be a major problem in the design of modern highways in Indiana, i.e., the current design standards circumvent these problems, except under very special localized circumstances. However, as pointed out by Osborne (52) in his study entitled "Feasibility

of Cold Weather Earthwork in Indiana", meteorological factors may soon require closer scrutiny.

### Physiography

#### Elements of Physiography

As stated by Witczak (74), "In the simple view, physiography permits subdivision into areas of contrasting or distinctive topographic expression. Such division is effected by an examination of three geomorphic control factors, viz., structure, process, and stage (63).

"Structure is a comprehensive term defined in (63) as "... all those ways in which earth materials out of which landforms are carved differ from one another in their physical and chemical attributes". In a sense, structure expresses the type and arrangement of parent materials.

"Process describes the factors of origination and modification primarily responsible for the landscape. Processes may act constructively or destructively and may originate above the earth surface (e.g., wind, water, ice) or below it (viz., diastrophism or vulcanism). Thus process may be interpreted as origin.

"The operation of process upon structure in the development of the landscape involves various evolutionary phases or stages. Thus, this term conveys the notion of time of aging under ambient climate conditions, or the factors of age.

"In summation, the topographic expression is a function of the geologic parent material, the geomorphic processes acting, and the time and climate of action. These factors are highly relevant to landscape classification for engineering purposes, although they are probably not sufficiently quantified".

A physiographic unit is characterized by a mode of topographic expression which is different from those of adjacent units. However, certain variations from the modal pattern occur and these variants are included as a matter of necessity. It is therefore logical that the physiographic subdivision become more "homogeneous" as the division become more limited in size. Malott (43) recognized this about 50 years ago when he outlined the basic physiographic subdivisions of Indiana, and described them in considerable detail.

The topography of Indiana is shown by Figure M-1. It is called "Topographic Map of Indiana", prepared by M. W. Logan, State Geologist. It has a 100 ft. contour interval, and has been reduced to about 1/3.7 of its original size for convenience of preparation.

#### Physiography of Indiana

The State of Indiana lies within the Central Plains physiographic province of North America as determined by Atwood (3). In the classical scheme of Fenneman (17), the maximum extent of glaciation is the boundary between the Till Plains Sections of the Central Lowland Province and the Highland Rim and Bluegrass Section of the Interior Low Plateau Province to the south. Approximately the northern fourth of the state lies within the Eastern Lake Section of the Central Lowland Province.

Wayne (72) states that Indiana can generally be divided into three broad physiographic divisions trending in an east-west direction across the State. The central division, comprising about one third of the state area, is a depositional plain of low relief, underlain largely by thick glacial till and modified only slightly by postglacial stream erosion. It is called either the Central Drift Plain or the Tipton Till Plain.



FIGURE M-1  
Reference (39)



The northern division is called the Northern Lake and Moraine Region and comprises slightly less than one fourth of the state area. It is divided into five subdivisions; the names, areas and percentages of State area for each subdivision are given in Table 1. The northern division is characterized by greater relief than the central division, being very hilly in some areas; but even in these areas, the uplands are interrupted by lowlands and plains of little relief. Landforms in this division are mostly of glacial origin. A large variety of depositional forms is present, including end moraines, outwash plains, kames, lake plains, valley trains and kettle holes, as well as many related post glacial features such as lakes, sand dunes, and peat bogs.

The roughest topography in Indiana is formed in the southern division, which is divided into seven subdivisions, (See Table 1). Landforms in this division are primarily the result of normal degradational processes, such as weathering, stream erosion, and mass movement. The middle part of the southern division was not glaciated and the topography strongly reflects the nature of the parent bedrocks. The units on either side were glaciated, but the influences of glaciation were minor and the physiography is largely bedrock controlled. An exception in part is the Wabash Lowland where many lacustrine areas, valley trains and outwash plains have developed as a result of glacial activity.

The following is a description of each physiographic unit taken largely from Wayne (72), which is basically a development of the classical work of Malott (43). The physiographic units and their geographic locations are shown in Figure 1. Some of the descriptions are after Schneider (58).

Table 1

Physiographic Regions as Approximate Percentages  
of Total Area for State of Indiana

Physiographic Region	Approximate Area sq. mi.	Approximate Percentage Total Area
1. Northern Lake and Moraine Region		
A. Calumet Lacustrine Plain	279	1
B. Valparaiso Morainal Area	619	2
C. Kankakee Outwash and Lacustrine Plain	3,256	9
D. Steuben Morainal Lake Area	3,684	10
E. Maumee Lacustrine Plain	146	Negligible
2. Tipton Till Plain	13,435	37
3. Dearborn Upland	1,829	5
4. Muscatatuck Regional Slope	1,653	5
5. Scottsburg Lowland	1,493	4
6. Norman Upland	1,233	3
7. Mitchell Plain	1,295	3
8. Crawford Upland	2,432	7
9. Wabash Lowland	4,937	14
Total	36,291 sq.mile	100%



## 1. Northern Lake and Moraine Region

### A. Calumet Lacustrine Plain

This physiographic subdivision is an area which was covered by waters of glacial Lake Chicago. It lies south of the present shore line of Lake Michigan and its southern boundary is the Glenwood beach along the north edge of the Valparaiso Morainal Area. Most of the subdivision gives the appearance of a nearly flat lacustrine plain, except for dunes along the present and former shore lines. The thickness of the unconsolidated deposits in this area vary between less than 50 ft. to more than 200 ft., as determined from Wayne's thickness of drift map (72).

### B. Valparaiso Morainal Area

As previously stated, the northern boundary of this physiographic subdivision forms the southern boundary for the Calumet Lacustrine Plain. The southern edge of the moraine is generally considered to represent the terminal position of the Lake Michigan Lobe during the Cary Substage of the Wisconsin Stage. The Valparaiso Moraine is about 150 ft. higher than the Calumet Lacustrine Plain. This relief can be clearly seen on the Physiographic Diagram of Indiana, Figure 2. Glacial drift extends beneath the moraine from less than 50 ft. to more than 250 ft. in depth.

### C. Kankakee Outwash and Lacustrine Plain

South and southeast of the Valparaiso Morainal Area, and extending from Illinois to Michigan in northwestern Indiana, is a nearly flat area of sandy lacustrine plain, outwash plain, and valley trains associated with the Kankakee, St. Joseph, Tippecanoe, and Iroquois Rivers.



FIGURE 2  
PHYSIOGRAPHIC  
DIAGRAM  
OF  
INDIANA

0 20 40  
MILES

(MODIFIED: 10-6-69)

referred to by Wayne (72) as the Kankakee Outwash and Lacustrine Plain. Much of this area is low and poorly drained. Relatively low sand dunes are common in this area. Thick gravel deposits below or interbedded with the surficial sandy sediments partly confirm the outwash origin of the material. Much of this area is underlain by thin drift over a nearly flat bedrock surface. The drift isopachs indicate a thickness varying from less than 50 ft. to more than 400 ft.

#### D. Steuben Morainal Lake Area

The Steuben Morainal Lake Area lies in northeastern Indiana to the east of the Kankakee Outwash and Lacustrine Plain. Its topographic expression and physiographic history is very complex. In some areas, the topography is nearly as rugged as in the bedrock uplands of southern Indiana. Maximum local relief on the order of 100 to 150 ft. is not uncommon, and in some cases it exceeds 200 ft. Recessional moraines of the Huron-Saginaw ice lobe constitute much of the surface, along with the northern limbs of the Ontario-Erie lobe moraines of the Wisconsin ice sheet. Knob and kettle type end moraine topography is evident nearly everywhere in the massive Maxinkuckee, Packerton, and Mississinewa Moraines. Many of the knobs known as kames and kame complexes are common in this subdivision. The kettles or ice-block depressions serve as basins for the thousands of lake and peat bogs that characterize northeastern Indiana, and set it apart from the rest of the state. The valley train and outwash plain deposits form a most complicated network in this region. Small lake beds are common and sand dunes are present in places, but in minor amounts. The thickness of drift in this subdivision varies from less than 50 ft. to more than 500 ft., although the contours shown

in Wayne's thickness of drift map (72) are very generalized due to lack of complete detailed information.

#### E. Maumee Lacustrine Plain

The flat abandoned floor of glacial Lake Maumee located in northeastern Indiana north and east of Ft. Wayne, is called the Maumee Lacustrine Plain. It is similar in topographic expression to the Calumet Lacustrine Plain in northwestern Indiana. The area is nearly level being generally at an elevation of 750 ft. Except for a beach line northeast of Ft. Wayne, 10 to 20 ft. high, and the narrow valley of the Maumee River, 20 to 40 ft. deep, the lake plain is virtually featureless. The thickness of unconsolidated deposits in this area is from less than 50 ft. to more than 150 ft.

#### 2. Tipton Till Plain

Wayne (72) states, "The largest physiographic unit in Indiana is the broad plain which lies south of the Wabash and Eel Rivers and immediately north of the regional units developed on bedrock in southern Indiana called the Tipton Till Plain by Malott (43)". In the western part of the state the southern boundary of this region is effectively determined by the Shelbyville Moraine. The southern boundary in the eastern portion of the state is not so well defined. It is drawn arbitrarily along the north edge of a broad transitional zone in which the topography is similar to that of the till plain but in which glacial drift is not sufficiently thick to completely obscure the general bedrock physiographic units. The region is characterized by little relief and only slight modification by post-Wisconsin streams. Throughout much of the region, the plain is virtually featureless; even most of the terminal

moraines included in this area are poorly developed, and have slopes. The monotonous topography of the till plain is broken by low eskers, esker troughs, and melt water drainage ways, most of which trend in a general northeast-southwest direction and form a conspicuous subparallel drainage pattern. The drift in this physiographic region varies from less than 50 ft. to more than 400 ft.

### 3. Dearborn Upland

A dissected plateau north and west of the Ohio River in extreme eastern Indiana makes up the physiographic subdivision known as the Dearborn Upland. Some parts of the plateaus are thoroughly dissected, but upland areas away from the stream are well preserved and in some cases even unmodified. The upland areas are considered to be part of the Lexington and Highland Rim Peneplain, a gently rolling erosion surface of the eastern interior United States postulated to have formed only a few hundred feet above sea level and to have been uplifted to its present elevation in Tertiary times. The area is characterized by smooth, moderate slopes and long, flat-topped fingers of upland between deeply entrenched valleys. It has been glacially modified and is underlain by flat-lying bedrock. The Laughery Escarpment occurs near the western boundary of this physiographic unit.

### 4. Muscatatuck Regional Slope

West of the Dearborn Upland is a gently westward-dipping structural plain known as the Muscatatuck Regional Slope. It is covered with Illinoian drift in Indiana and can be recognized for a short distance north of the Wisconsin glacial boundary. The northern boundary of this region has been placed along the upper reaches of a large bedrock

valley in southern Hancock County and across Henry County. Valleys of this subdivision are commonly steep sided and moderately deep, the streams having downcut through an average 20 to 25 feet of unconsolidated cover and into the underlying consolidated deposits. Drainage development and stream entrenchment are less advanced in the eastern or upstream section of the unit than farther west. Upland areas are generally very broad and nearly flat to undulating, indicating that the region is still in the youthful stage of landform development. The glacial deposits range in thickness from less than 50 ft. to more than 200 ft.

#### 5. Scottsburg Lowland

The Scottsburg Lowland is a linear belt of low relief lying to the west of the Muscatatuck Regional Slope, and merging with it without a distinctive topographic break. Geomorphically speaking, this subdivision is a strike valley controlled by the underlying bedrock formations. In cross section the lowland is a strongly symmetric trough, with its more gentle eastern slope cutting obliquely across the gently westward dipping consolidated deposits. The Knobstone Excarnation rises abruptly above the west edge of the lowland to form its boundary. Glacial deposits thickening to the north entirely obscure this lowland. The lowland is primarily the result of more rapid erosion of the less resistant consolidated deposits in this region. The present topography includes some flat portions near the Tipton Till Plain boundary, a few weakly developed moraines, and slight glacial dissection. Drift thickness reaches as much as 400 ft. or more.

#### 6. Norman Upland

Forming the western boundary of the Scottsburg Lowland is an



east-facing cuesta scarp called the Knobstone Escarpment. This escarpment is the most prominent regional topographic feature in the State. This fact is dramatically portrayed on the physiographic relief diagram included as Figure 2. North of the Ohio River near New Albany, the escarpment is particularly prominent, with its crest about 500 to 600 feet above the lowland valleys to the east. It decreases in height to the north and disappears under the glacial till as the Tipton Till Plain is approached. The western boundary of the upland is gradational and is drawn where sink holes of the karst plain to the west become predominant over valleys that have been eroded by running water. The Norman Upland is a remnant of the late Tertiary Lexington peneplain, according to Malott (43). The area has strong local relief and is characterized generally by flat-topped narrow divides, steep slopes, and deep V-shaped valleys. The area is nearly all in slope, and is drained by a well developed dendritic drainage system. Deep re-entrants through which large preglacial valleys entered the Norman Upland from the east exist in the almost solid front of the Knobstone escarpment. An example is the junction of the Muscatatuck River and the East Fork White River. Glacial drift is less than 50 ft. over much of the upland, and outcrops are fairly common. Drift extends to more than 200 ft. over the entrenched bedrock valley to the north.

#### 7. Mitchell Plain

To the west of the Norman Upland lies a karst upland known as the Mitchell Plain. Limestone used for building purposes is quarried from the Salem Formation within this region. Solution features in the younger St. Louis and Ste. Genevieve Formations give this region the

highest sink hole concentration per unit area in the state. More than 1,000 sink holes were counted in a square mile near Orleans (58). These depressions are basins into which surface runoff readily drains. Thus, the drainage is mostly underground; minor surface streams may drain into the sink holes. Small ponds or lakes form where sink holes have been plugged by natural processes or the activities of Man. Beneath the surface the bedrock is punctured with an endless system of channels and caverns. The Mitchell Plain is an area of low relief except in its western part where it is marked by numerous outliers or detached hills of the adjacent Crawford Upland and in a few places where it is crossed by deeply entrenched surface streams. The drift ranges from a negligible thickness to as much as 150 ft., or possibly more.

#### 8. Crawford Upland

The boundary between the Mitchell Plain and the Crawford Upland lying to the west is generally irregular, although exceedingly sharp just north of the Ohio River. It is drawn along the base of the Chester escarpment, an east-facing cuesta scarp capped by resistant rocks. The eastern part of the Upland is characterized by numerous springs and by Indiana's best known caverns, including Wyandotte and Marengo Caves. Differential erosion of the diverse lithologic units has produced a deeply dissected upland marked by a great diversity of topographic features. Malott (43) considered this area to have the most rugged topography and the greatest variety of landforms of any part of Indiana. The area is considered to be a remnant of the Lexington peneplain. The Crawford Upland is a naturally dissected westward-sloping plateau characterized by a well dispersed drainage system. The bottom of the larger



valleys are occupied by moderately wide flood plains, providing the only level terrain in some areas. Drift is thin over most of the preglacial upland, with thick drift being limited largely to buried valleys.

#### 9. Wabash Lowland

The Crawford Upland grades westward into the Wabash Lowland in the southwestern corner of the State. The Lowland is the largest of the southern Indiana physiographic subdivisions (58). It has comparatively little relief and extensive aggraded valleys, which are largely the result of Pleistocene deposition. Much of the area is covered by glacial till, which is underlain by widespread and in places thick lacustrine, outwash, and alluvial sediments. The most conspicuous deposits are the broad, terraced valley-fill materials along the Ohio, Wabash and White Rivers, but broad flat bottom lands underlain by slackwater sediments are present along many of the tributary streams. Upland tracts are described as undulating to rolling plains (58). Deposits of wind blown sand or silt (loess) blanket much of the upland surface and form the upper valley walls in some places, particularly along tributary valleys near the Wabash River. In general, the thickness of aeolian sediments decreases eastward from the Wabash River.

#### Physiographic Regions for Landslide Severity

A regional approach has been used generally to assess the landslide severity of the United States. The "Physiographic Regions for Landslide Severity" are shown in Table 2, based on Highway Research Board questionnaires and literature search. Figure 3 shows the location of the various regions and their ratings. Four ratings were used by Baker and Gray (4): Major severity, minor severity, medium severity and landslide problem

TABLE 2

## Physiographic Regions for Landslide Severity

- |  |  |
|--|--|
| <p>I. <i>Major severity</i></p> <p>8d. Allegheny Mountain Section</p> <p>8e. Kanawha Section</p> <p>14a. Springfield-Salem Plateaus</p> <p>16. Southern Rocky Mountains</p> <p>19. Northern Rocky Mountains</p> <p>20a. Walla Walla Plateau</p> <p>23a. Northern Cascade Mountains</p> <p>24a. Puget Trough</p> <p>24b. Olympic Mountains</p> <p>24c. Oregon Coast Range</p> <p>24d. Klamath Mountains</p> <p>24f. California Coast Ranges</p> <p>24g. Los Angeles Ranges</p> <p>II. <i>Medium severity</i></p> <p>5b. Southern section of the Blue Ridge Province</p> <p>6b. Middle section of Valley and Ridge Province</p> <p>8c. Southern New York Section</p> <p>11b. Lexington Plain</p> <p>12d. Till Plains of the Central Lowland Province</p> <p>12e. Dissected Till Plains of the Central Lowland Province</p> <p>18. Middle Rocky Mountains</p> <p>20c. Payette Section</p> <p>20d. Snake River Plain</p> <p>III. <i>Minor severity</i></p> <p>1. Superior Upland</p> <p>3a. Embayed Section</p> <p>3c. Floridian Section</p> <p>3d. East Gulf Coastal Plain</p> <p>3e. Mississippi Alluvial Plain</p> <p>4a. Piedmont Upland</p> <p>4b. Piedmont Lowlands</p> <p>6c. Hudson Valley</p> <p>7a. Champlain Section</p> <p>9b. New England Upland Section</p> <p>9c. White Mountain Section</p> <p>9d. Green Mountain Section</p> <p>9e. Taconic Section</p> <p>11a. Highland Rim Section</p> <p>12a. Eastern Lake Section</p> <p>12b. Western Lake Section</p> <p>12c. Wisconsin Driftless Section</p> <p>12f. Osage Plains</p> <p>13a. Glaciated Missouri Plateau</p> <p>13b. Unglaciated Missouri Plateau</p> | <p>13c. Black Hills</p> <p>13d. High Plains</p> <p>13e. Plains Border</p> <p>13f. Colorado Piedmont</p> <p>14b. Boston "Mountains"</p> <p>21a. High Plateaus of Utah</p> <p>21b. Uinta Basin</p> <p>21c. Canyon Lands</p> <p>21d. Navajo Section</p> <p>21e. Grand Canyon Section</p> <p>22a. Great Basin</p> <p>22d. Mexican Highland</p> <p>22e. Sacramento Section</p> <p>23b. Middle Cascade Mountains</p> <p>23c. Southern Cascade Mountains</p> <p>23d. Sierra Nevada</p> <p>24e. California Trough</p> <p>IV. <i>Nonexistent problem</i></p> <p>2. Continental Shelf</p> <p>3b. Sea Island Section</p> <p>3f. West Gulf Coast Plain</p> <p>5a. Northern Section of the Blue Ridge Province</p> <p>6a. Tennessee Section</p> <p>7b. Northern Section of the St. Lawrence Valley Province</p> <p>8a. Mohawk Section</p> <p>8b. Catskill Section</p> <p>8f. Cumberland Plateau</p> <p>8g. Cumberland Mountains</p> <p>9a. Seaboard Lowland Section</p> <p>10. Adirondack Province</p> <p>11c. Nashville Basin</p> <p>11d. Western Section of the Interior Low Plateaus</p> <p>13g. Raton Section</p> <p>13h. Pecos Valley</p> <p>13i. Edwards Plateau</p> <p>13k. Central Texas Section</p> <p>15a. Arkansas Valley</p> <p>15b. Ouachita Mountains</p> <p>17. Wyoming Basin</p> <p>20b. Blue Mountain</p> <p>20e. Harney Section</p> <p>21f. Datil Section</p> <p>22b. Sonoran Desert</p> <p>22c. Salton Trough</p> <p>25. Lower California Province</p> |
|--|--|

Source: Based upon Highway Research Board questionnaires and partial literature search.

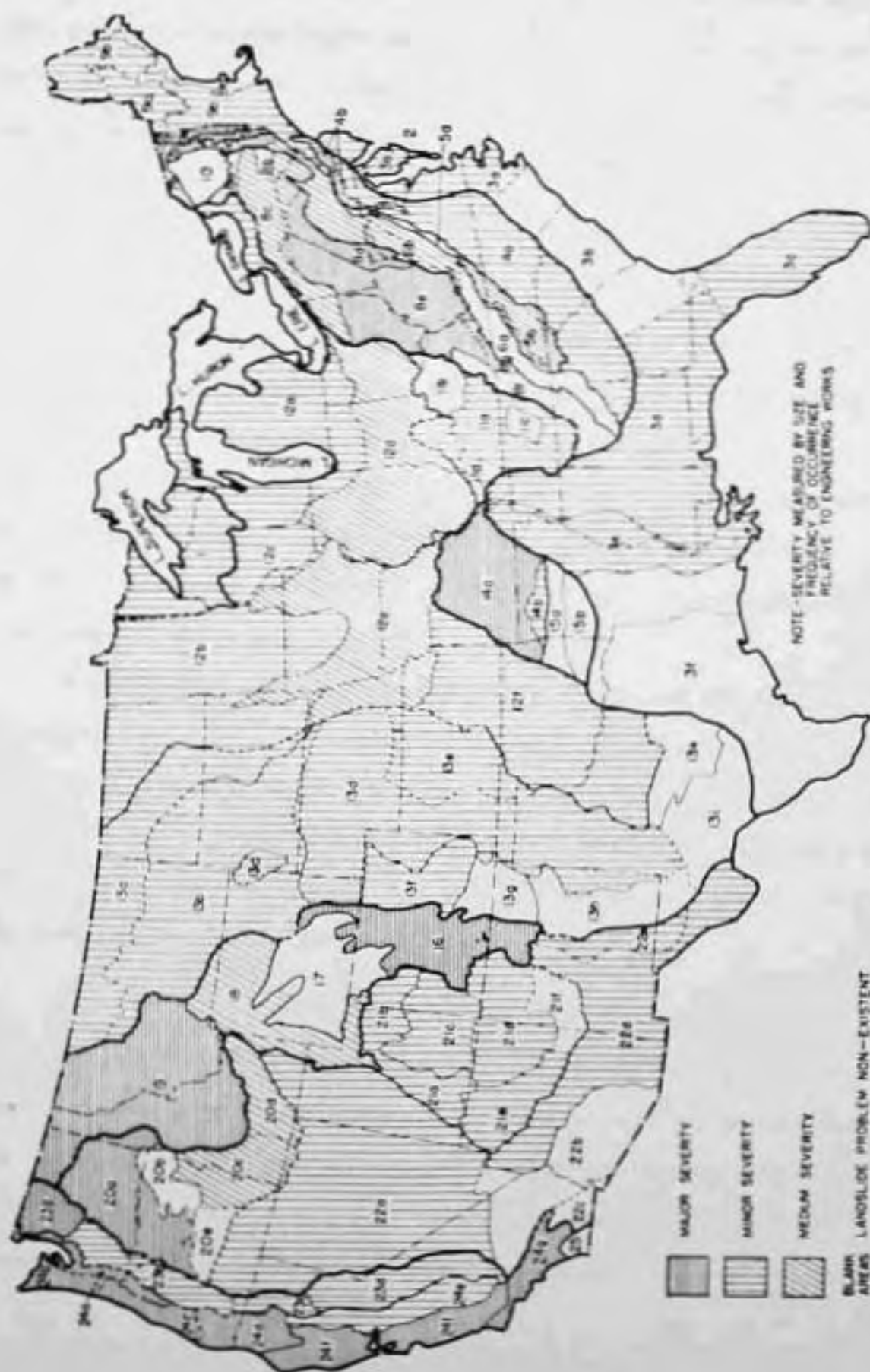


FIGURE 3 Landslide Severity of the United States

After Baker and Gray (4)

non-existent. The State of Indiana is rated primarily as medium severity, with the northern region and south central region having a minor severity rating. Since the ratings are based upon rather large physiographic sections, they are general.

### Geology

#### Glacial Geology

Most of the surface of Indiana has been glaciated to varying degrees by the various continental glacial advances. The limits of the various glacial stages and substages are shown in Figure 4 for the Central United States. The south central portion of the State was not affected by the sculptoring effects of the ice sheet, thus the topography, drainage and soils have been formed through the weathering of the Paleozoic sediments.

Reference (73) shows the various glacial formations and landforms throughout the State. The lacustrine deposits resulting from Illinoian and Wisconsin Glacial Stages are mapped in some detail by Thornbury (62). A map showing the thickness of drift north of the Wisconsin glacial boundary has been prepared by Wayne (72) and is included as Figure 5. It has been reduced in size for convenience of presentation.

#### Bedrock Geology

An excellent and thorough account of the bedrock geology and stratigraphy is presented in the Handbook of Indiana Geology by Cummings (10). The various bedrock formations along with their areal extent and several typical bedrock cross sections are shown on Reference (54). Bedrock physiographic units as shown in Figure 6 were originally developed by

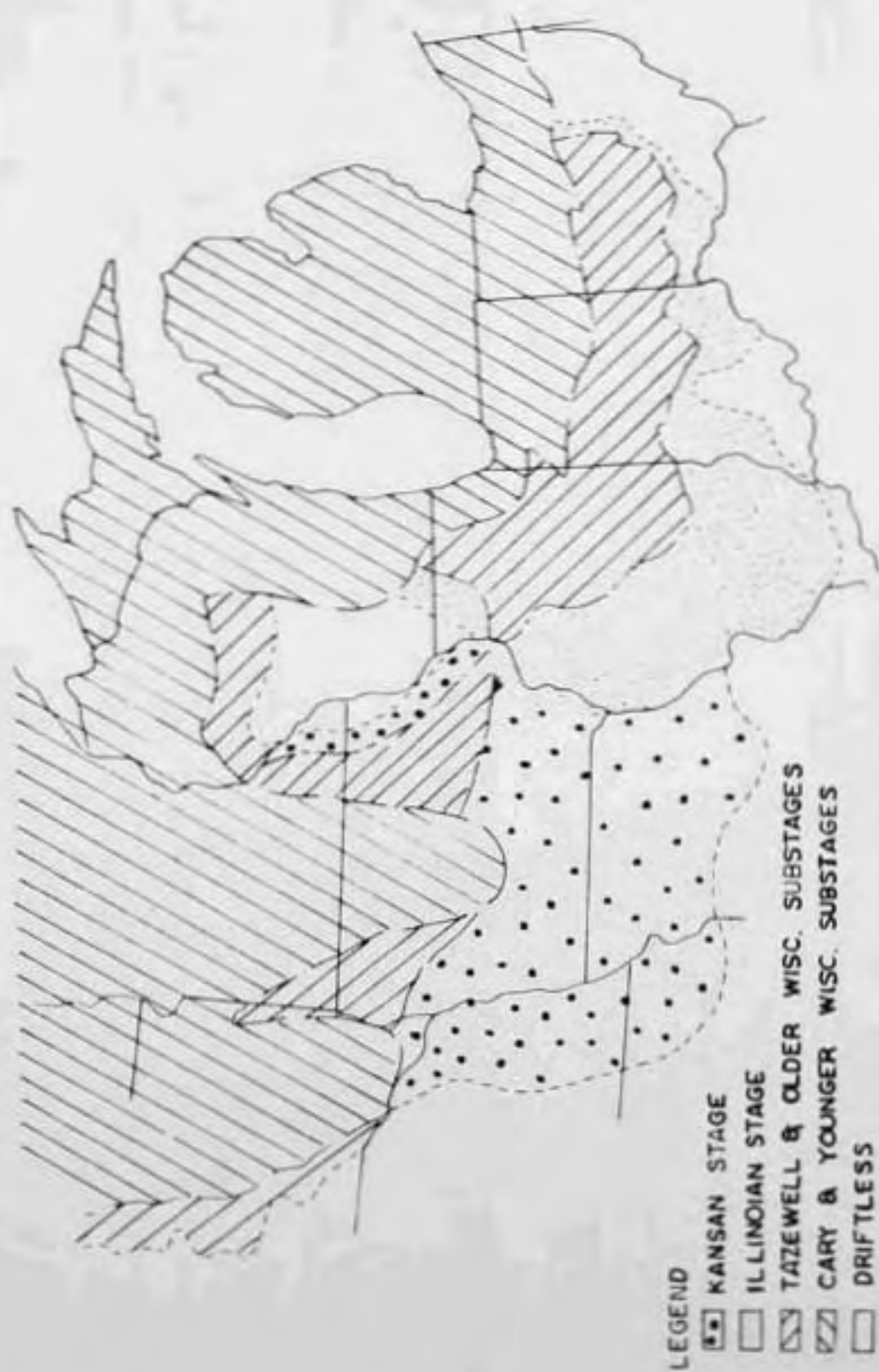
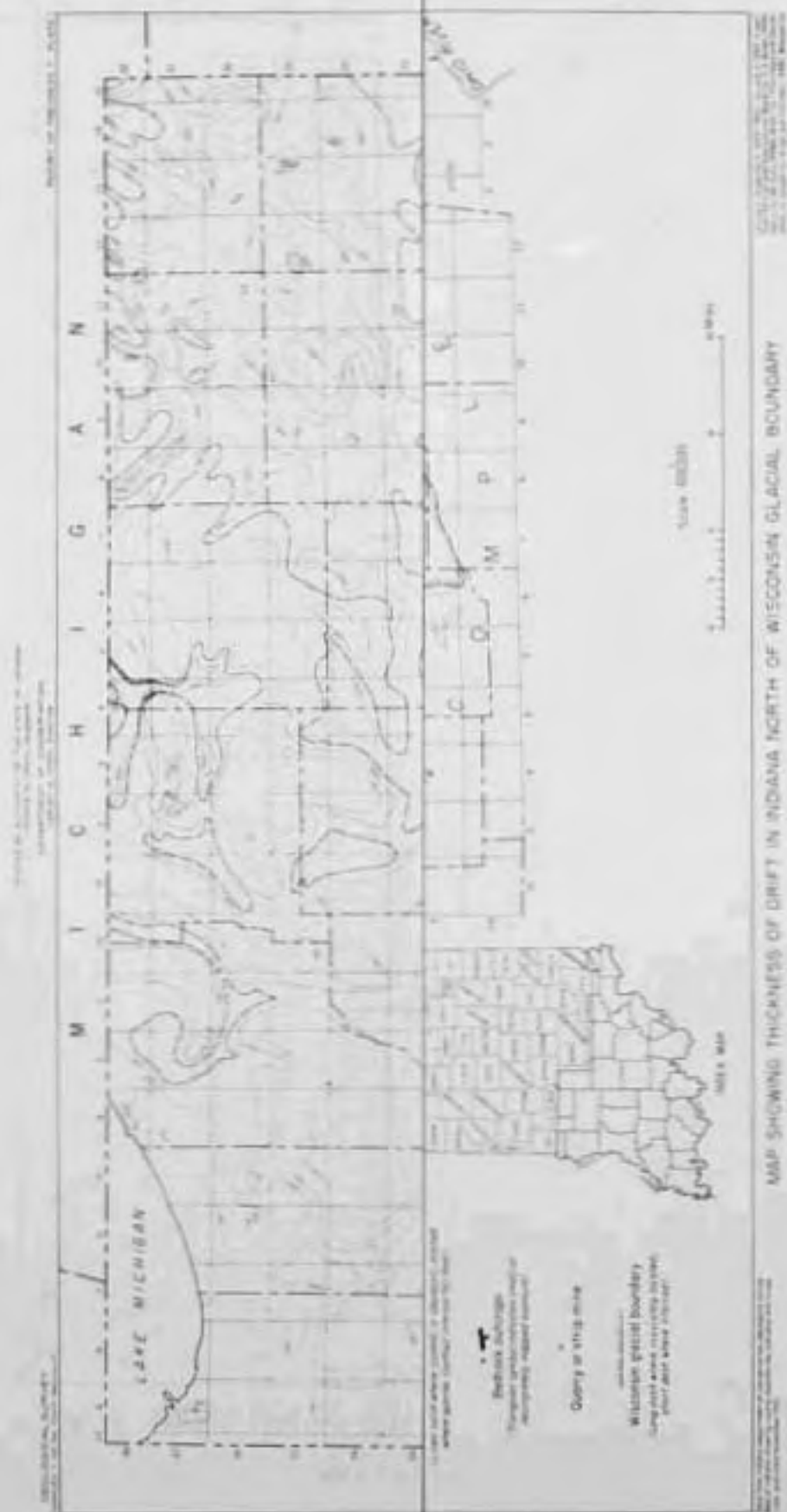


FIG. 4 DISTRIBUTION OF MAJOR ICE SHEETS IN THE CENTRAL PORTION  
OF THE CENTRAL AND EASTERN LOWLAND PROVINCE

Modified After Thornbury (64)



(72)

FIGURE 5



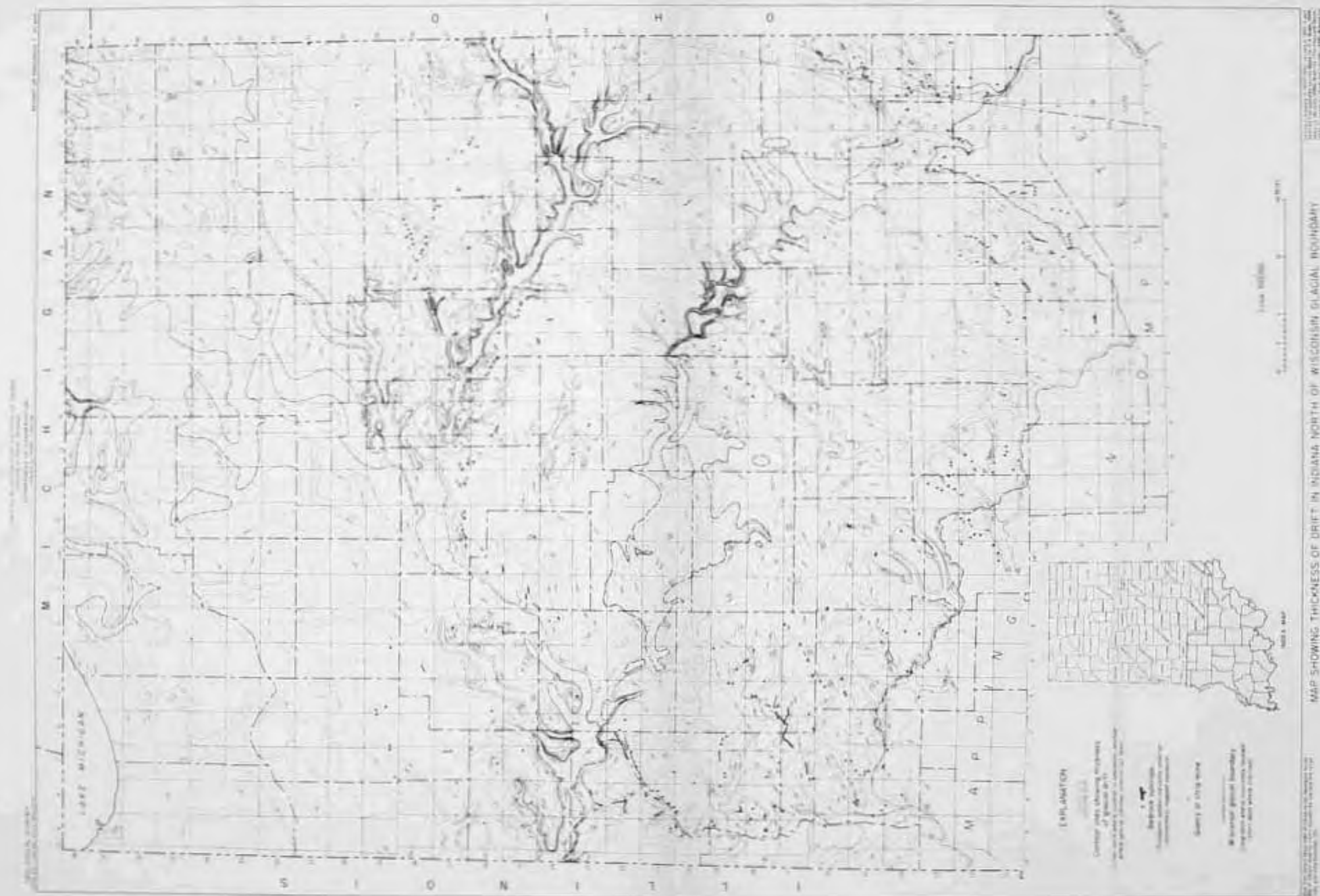


FIGURE 5





Fig 6 Map of Indiana showing bedrock physiographic units.

Modified After Wayne (72)

Malott (43) and subsequently modified by Wayne (72). The bedrock physiographic units in southern Indiana generally have north-south boundaries which conform to the physiographic subdivisions previously discussed. It can be clearly seen however, by comparison of Figures 1 and 6, that the east-west boundaries for the bedrock units extend much further north, reflecting the sub-surface bedrock geology. It can also be seen that the northern bedrock physiographic units have lateral limits very much modified from the previously discussed physiographic units.

The dominant lithologies of the various bedrock physiographic units can be found in Wayne (72) or in Figure 7. The formations and geologic age of these consolidated deposits are detailed in Cummings (10) and in Reference (46).

#### Pedology

References (5, 9, 20, 60 and 67) are on the pedologic approach to classification and distribution of Indiana soils. Reference (1) maps the pedologic soil associations and provides valuable soil series descriptions.

The Soil Conservation Service (SCS) has prepared four tabulations of soil indices and interpretative ratings of these soils for various related fields of interest to us and practical applications. The SCS Table No. 1, our Table A-1 included in Appendix A, is entitled "Brief Description of Soils of Indiana and their Estimated Physical and Chemical Properties"; the second SCS table; our Table A-2, is entitled "Interpretation of the Soils in Indiana for Rural and Urban Development"; SCS Table No. 3, is entitled "Interpretations of Engineering Properties of Major Soils in Indiana, Non-Agricultural (Urban)"; and SCS Table No. 4,

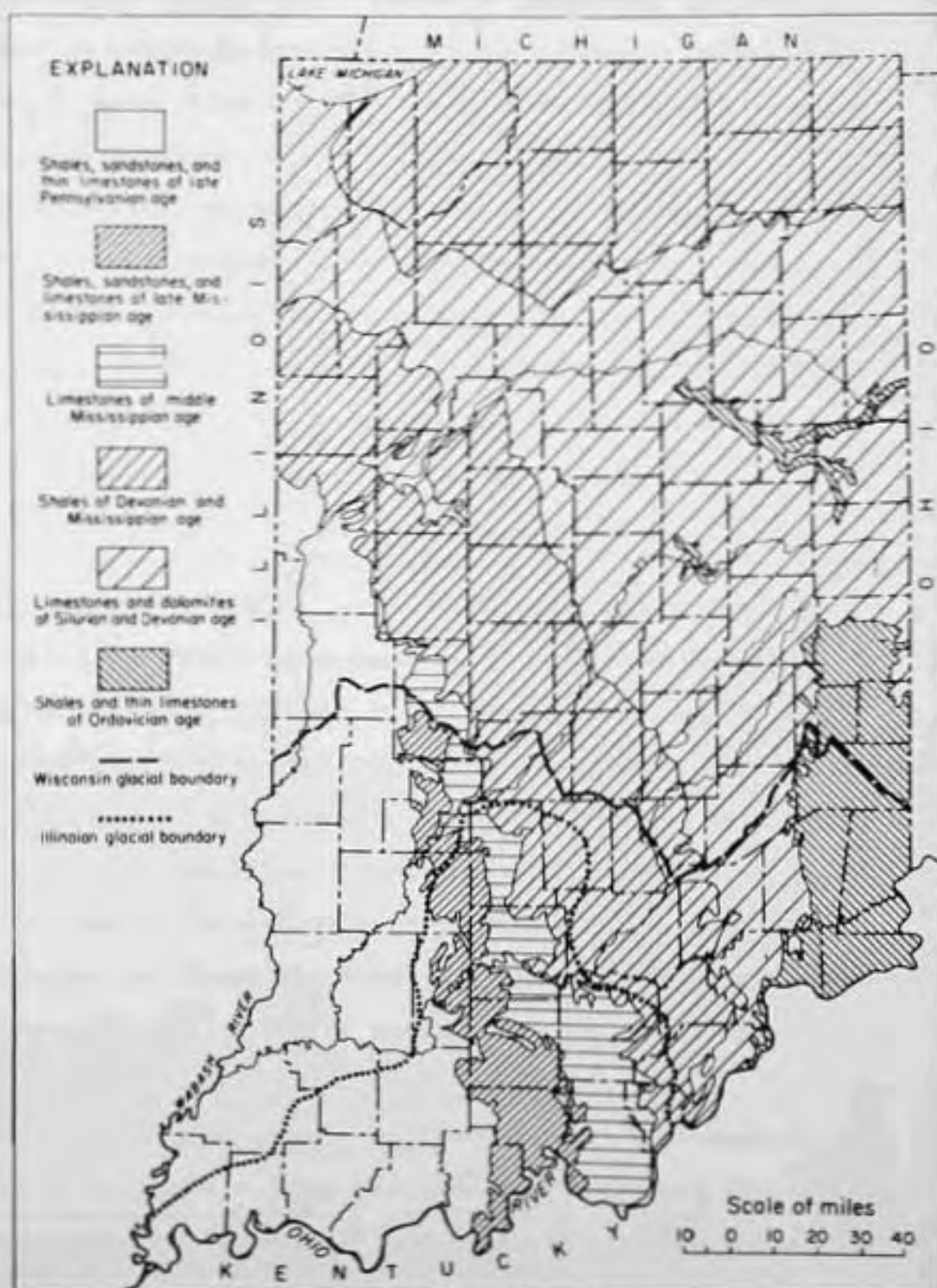


Figure 7 -Map of Indiana showing dominant lithologies of the bedrock.

After McGregor (46)

our Table A-4, is entitled "Interpretation of Engineering Properties of Major Soils in Indiana for Agriculture". Instructions for using these tables and a sample of the data from them have been included in Appendix A of this presentation.

Figure 8 showing the "General Soil Regions", from Reference (9), was also useful in this research. Agricultural soil mapping on a county basis is available for many Indiana counties. The "Status of Agricultural Soil Mapping in Indiana" is included in Appendix B of McKittrick's Thesis (48), page 167, and Table B-1 of that thesis gives "Ratings and Availability of Agricultural Soil Surveys in Indiana" on page 170.

#### Remote Sensing

Important pioneer work in the interpretation of general soil conditions from black and white stereographic aerial photographs was undertaken at Purdue University in the 1940's. Although many parts of the electromagnetic spectrum are now being studied for interpretation of surface feature, only the black and white coverage is currently used in a routine manner in Indiana. Aerial photographic interpretation has been the dominant tool in the preparation of county engineering soils maps. The "Availability of County Engineering Soil Maps prepared by the use of Aerial Photographs" is included in Appendix C, Table C-1, on page 174 of McKittrick (48)<sup>1</sup>.

Several of the county reports were very useful in this research, viz., (5, 18, 48, and 55). Other excellent reports have been prepared

<sup>1</sup> The following counties have been mapped since McKittrick's thesis: Allen, Benton, Carroll, DeKalb, Fayette, Fulton, Harrison, Howard, Madison, Noble, Owen, Perry, Sullivan, Union and White. It is expected that mapping will be completed for Miami, Wabash and Warren Counties in 1970.

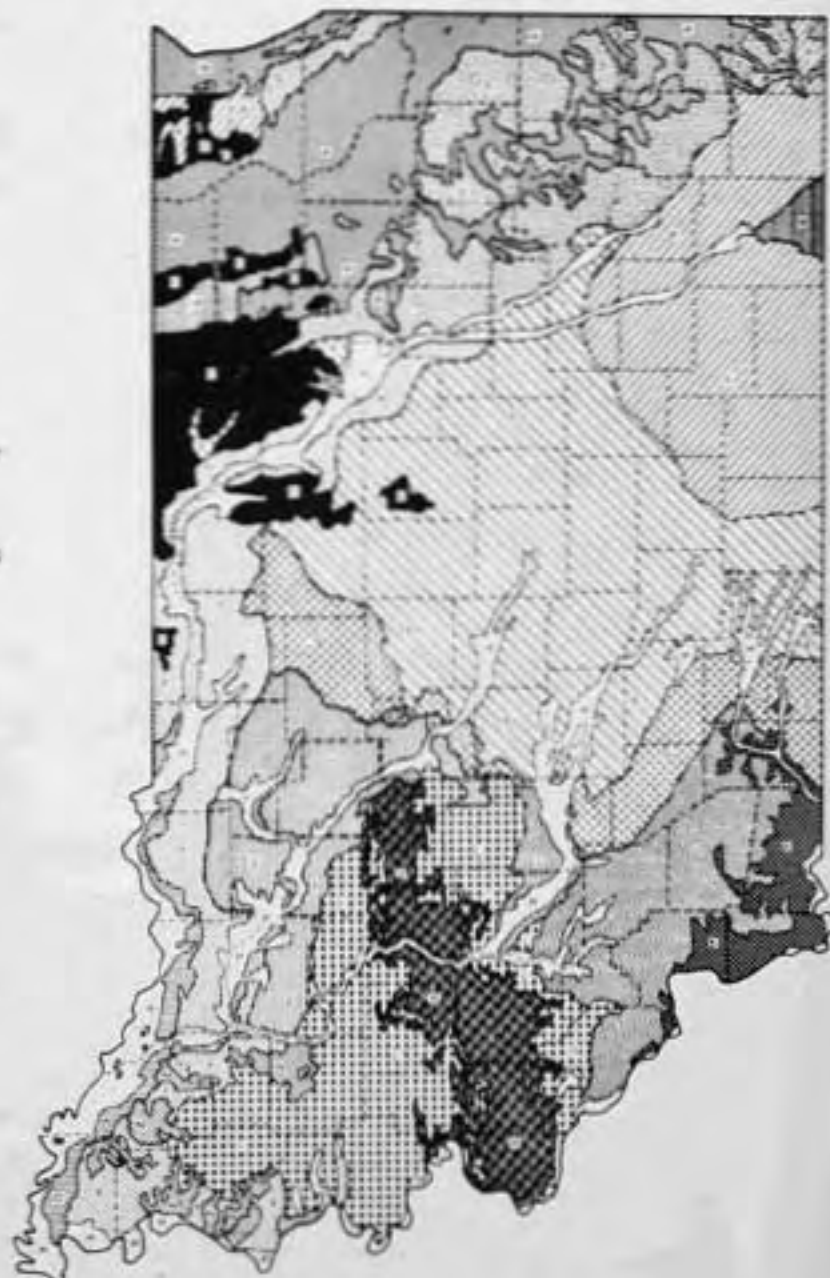


Figure 8 GENERAL SOIL REGIONS

After Bushnell (9)



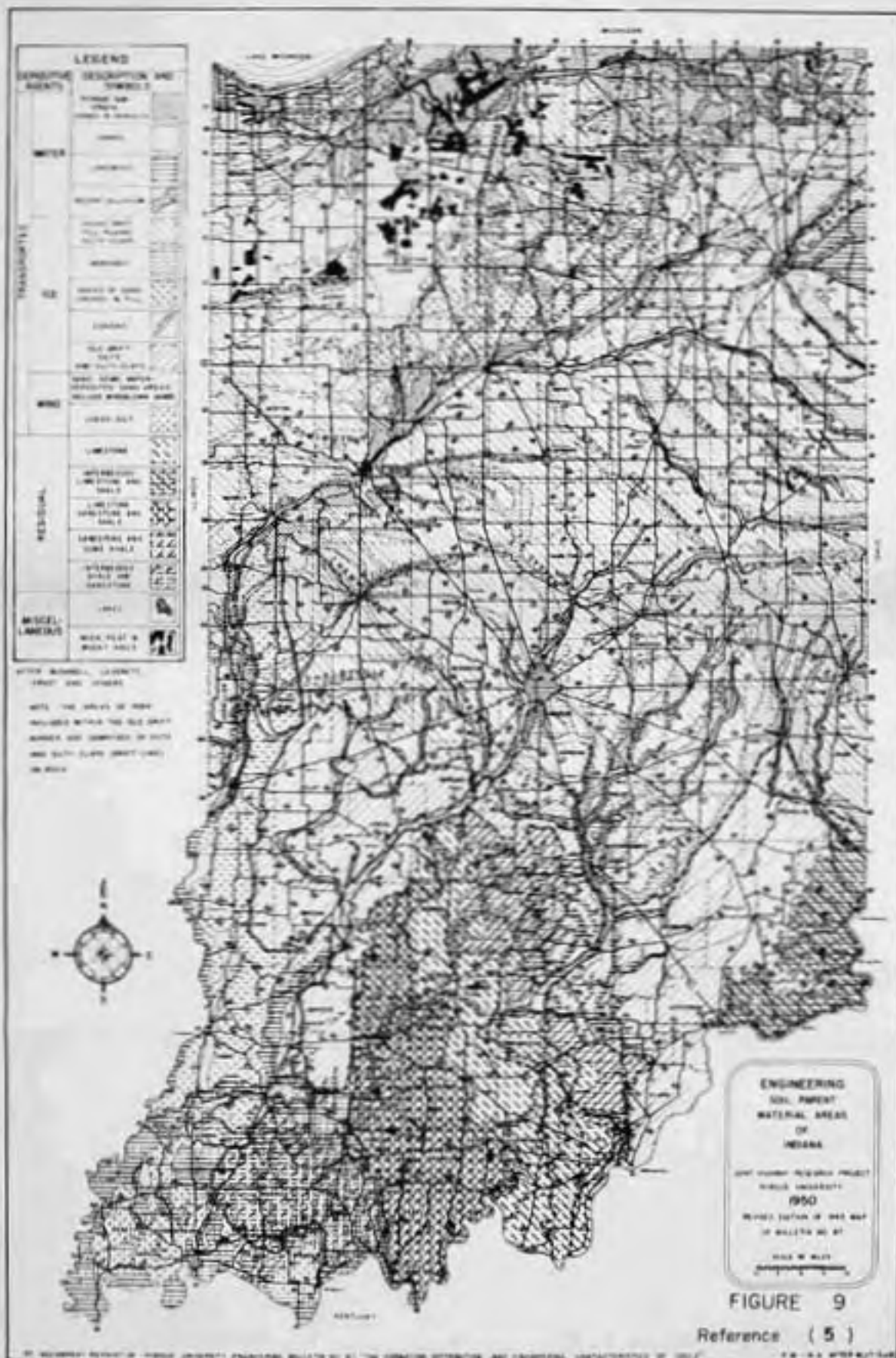
as a part of the Joint Highway Research Project for air-photo interpretation of some major parent material regions in Indiana. These have been summarized by McKittrick (48) on page 175 under "Bibliography of Special Air-Photo Studies and Reports in Indiana".

#### Engineering Soils

The mapping of soils and rocks depends most strongly in its form upon, (a) the scale, and (b) the perspective and objective of the mapper. All maps are generalizations, and the smaller the scale the greater the degree of generalization. All mapping needs to be based upon descriptors which are relatively simple and easy to determine. The description chosen by the engineer are those which are both convenient and highly useful for framing the general nature of design and construction problems. Such maps provide valuable insight for preliminary studies such as route location and setting up a boring program for any given project. On occasion they may substitute for field studies, e.g., where the latter do not appear economically justifiable.

An outstanding effort to map and describe the soils of Indiana, drawing heavily on available pedologic data, was made by Belcher, Gregg and Woods in their Bulletin 87 entitled, "The Formation, Distribution and Engineering Characteristics of Soils" (5). This work led to a map of "Engineering Soil Parent Materials of Indiana, Figure 9.

As previously mentioned certain county engineering soils maps have been prepared through interpretation of black and white aerial photography, usually supplemented by limited boring, sampling and testing. As might be expected the county maps give more detail due to the larger scale.





### Drainage and Topography

Very complete drainage maps are available for all Indiana counties, Parvis (55). These were compiled to compensate for the (then) inadequate topographic mapping of the State. The Index to Topographic Maps of Indiana (33), reflects a larger amount of recent effort. Since topographic position and relation to drainage ways can be important predictors of soil type and moisture conditions, such maps serve the soils engineer in his preliminary assessments.

### Aggregates

An important aspect of highway engineering is the source of available aggregates for base, subbase and wearing courses. The predominant sources in Indiana are sand-gravel and crushed carbonate rocks. Illustrations have been included to show the crushed stone quarry operations, Figure 10, the glacial deposits of sand and gravel, Figure 11, and sand and gravel pit operations, Figure 12.



FIGURE 10 CRUSHED STONE OPERATION  
Modified After (38)

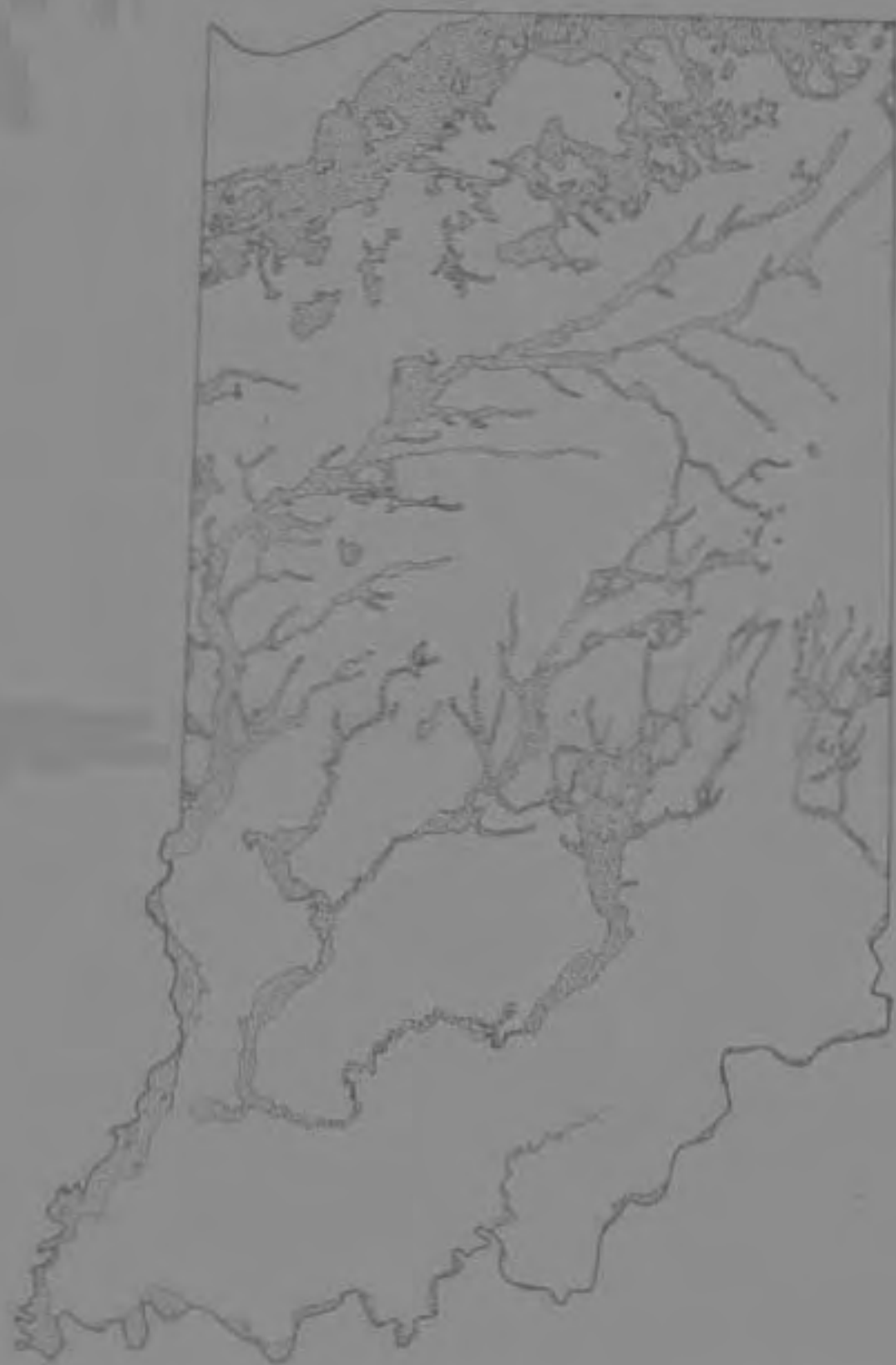


FIGURE 11 MAP OF INDIANA SHOWING GLACIAL  
DEPOSITS OF SAND AND GRAVEL.

Modified after [47]



SIGNIFICANT FACTORS INFLUENCING A REGIONAL  
APPROACH TO HIGHWAY SOILS CONSIDERATIONS

A critical step in the development of a practical and useful regional approach is the selection of the unit for which materials and problems are to be generalized. Use of the nine physiographic subdivisions of Wayne (72) was a compromise. More research would be required to determine the optimal units. In the development of a regional approach for highway soils considerations, several factors appear to be dominant. McKittrick (48), identified these factors as geologic origin and complexity of parent materials, topographic expression and general soil texture, including the approximate size of the clay fraction. An early challenge in this approach is the quantification of these or similar factors for the various physiographic subdivisions. The next step is the correlation of the quantified factors with pertinent considerations and/or problems of highway design and construction.

GENERALIZED QUANTIFICATION OF SIGNIFICANT FACTORS  
INFLUENCING A REGIONAL APPROACH TO HIGHWAY SOILS CONSIDERATIONS

Several original procedures were used generally to quantify the distribution of soil parent materials areas or landforms within each physiographic region. Other related factors were also investigated.

Methods of Generalized Quantification

A first and obvious step in generalized quantification was to compare the State physiographic regions with other state maps depicting topography, geology, pedologic units, engineering soil parent material areas, and thickness of drift. All of these maps were readily available. The comparisons are described in some detail below.

Topography

The topographic map by Logan (39) has a 100-foot contour interval and a scale of approximately 1:500,000 or about 1 1/4 inch to 10 miles. It is the largest scale state topographic map known to the writer. Since topography is considered to be a major factor, it was analyzed for each physiographic subdivision in a number of ways, e.g., the frequency distribution of elevation was defined. Areas within defined elevation intervals were planimetered, and curves of Terrain Elevation Interval vs. Percent Area Physiographic Region are included in Appendix B.

The Terrain Elevation Interval was investigated for correlation

with landforms and/or soil types within a physiographic region. It was determined that an elevation interval may be useful in a limited or localized area, such as defining consolidated formations in a stratigraphic column, or unconsolidated deposits of small areal extent. It was also determined that the elevation interval could not be used to define landforms in an area large as a physiographic subdivision, unless there was only one elevation interval and basically one parent material, such as in the Maumee Lacustrine Plain. That this is indeed the case can be demonstrated by a simple example. Let us take the stream deposits found in the Wabash River Valley within the Tipton Till Plain physiographic region. Clearly, for water to flow in the river, a gradient must exist. This gradient extended over an area as large as the Tipton Till Plain includes several elevation intervals. Thus, there is overlapping, and other landforms will be found within the same elevation interval. Also, in glaciated areas, deposition of ground moraine, end moraine, valley train, and outwash plain sediments may occur within any elevation interval under consideration.

Further study may show the elevation interval approach to have some useage in residual soil areas. However, it may be necessary to use a smaller contour interval than was applied in this study.

#### Thickness of Drift North of Wisconsin Glacial Boundary

The thickness of drift map was prepared by Wayne (72). The scale of this map is 1:500,000, or approximately 1 1/4 inch to 10 miles, and a contour interval of 50 feet is used. The thickness of unconsolidated deposits in Indiana south of the Wisconsin glacial boundary has not been



mapped to the present time. Since depth to bedrock or thickness of drift is an important factor for many engineering projects, a frequency distribution of depth was developed for each physiographic region. Areas between defined depth intervals were planimeted and distribution curves drawn. These curves show the Drift Depth Interval vs. Percent Area Physiographic Region, and are included in Appendix B .

It should be pointed out that the drift distribution curves for the Dearborn Upland, Muscatatuck Regional Slope, Scottsburg Lowland and the Norman Upland physiographic regions represent only a fraction of the total area of each region, since Wayne's map (72) extends only to the southern limit of the Wisconsin Glacial Boundary. The approximate percentages of the total area included are shown near the curves in Appendix B .

A map of the bedrock topography of Northern Indiana (7) is included as Figure M-2.

#### Engineering Soil Parent Material Areas

Such a map is available as a 1950 revision of the 1943 map of Bulletin No. 87 (5). The scale is approximately 3/4 inch equals 10 miles. The physiographic subdivisions were outlined on this map, and the area of each engineering soil parent material occurring with a physiographic region was planimeted. This information has been plotted as bar graphs of Soil Type (Parent Material) vs. Percent Area Physiographic Region, and included in Appendix C .

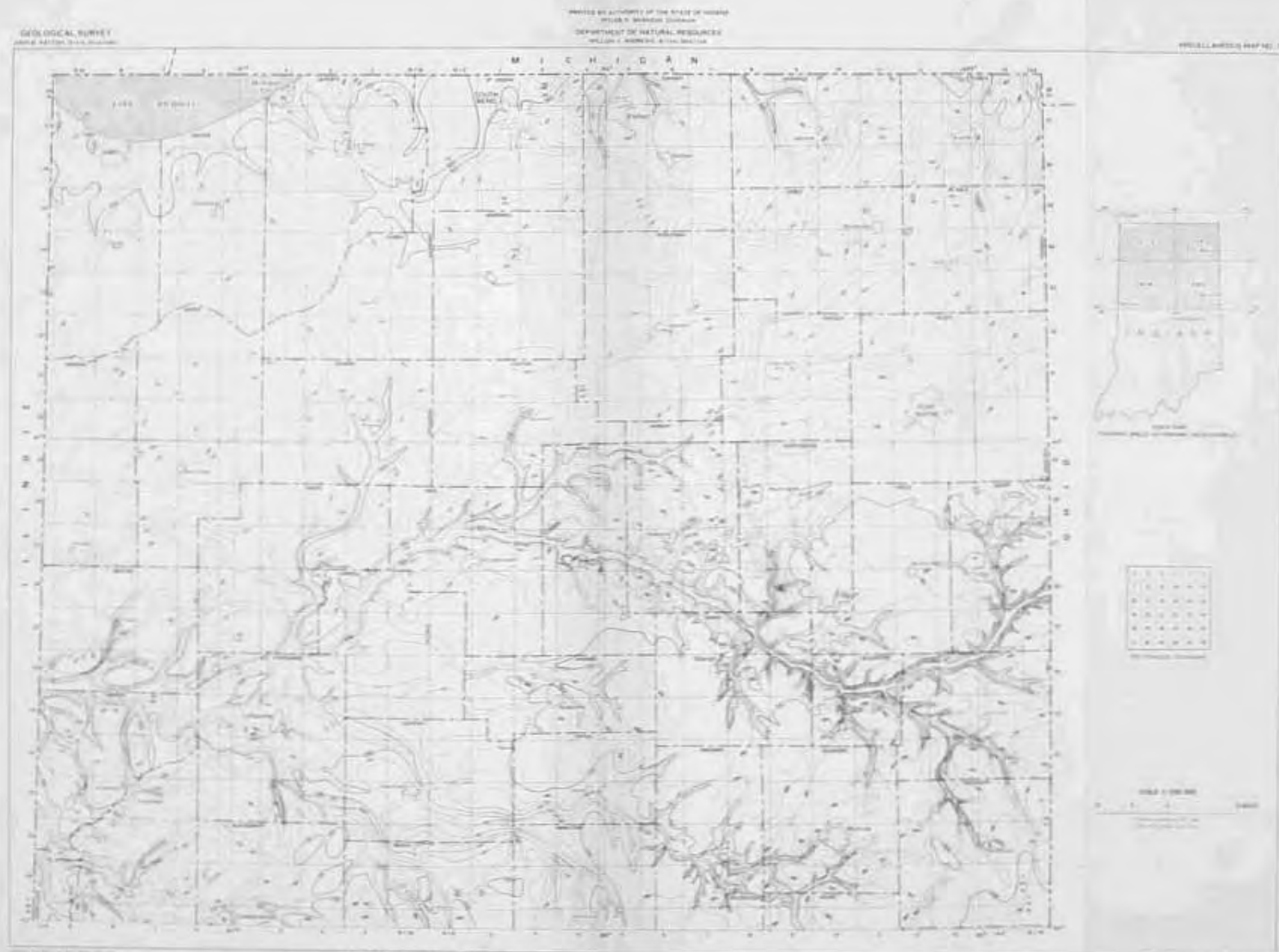


FIGURE M-2 MAP SHOWING BEDROCK TOPOGRAPHY OF NORTHERN INDIANA

By John W. Dwyer, Stanley J. Gifford, and William C. Kennedy

1960

Reference (7)

### Glacial Geology

The mapping is a part of the Atlas of Mineral Resources of Indiana (Map No. 10) and was prepared by Wayne (73) in 1958. The scale is 1:1,000,000 or approximately 5/8 inch equals 10 miles. It shows the predominant soil areas of glacial origin for the glaciated part of the State. Again frequency distribution bar graphs were plotted and are included in Appendix C .

### Pedology

A "Map of Indiana Soils" (1) shows Soil Regions (parent material areas) and associations of soil series within the Regions. In many areas of the State, the boundaries for the Soil Regions correspond to the boundaries of Figures 8 and 9, which emphasizes the probable utility of such mapping for engineering purposes. The four Tables prepared by the Soil Conservation Service, samples of which are included in Appendix A , are helpful in interpreting the pedologic mapping for engineering applications.

The physiographic subdivisions were transferred to the State Pedologic map and the area of each series association within a physiographic region was planimeted. This information has been shown in the form of bar graphs of Series Association Number vs. Percent Area Physiographic Region, in Appendix C .

### Normalized Earthwork Quantities by Physiographic Region

A further generalized quantification involved tabulating the earthwork quantities for Indiana highway projects within each physiographic region for Interstate, Primary and Secondary roads. Only those relatively

recent projects for which data were readily available were used. The Interstate, Primary and Secondary project data have been included in Tables 3, 4 and 5, respectively. A portion of the data for the Interstate projects was plotted as bar graphs of Physiographic Regions vs. Excavation or Special Borrow, Figure 13. These data serve as indicators of topographic variation or roughness of terrain. However, they are also a function of the standard requirements for alignment, grade and geometry of roadway cross-section for the various classes of projects.

#### Aggregate Availability and Use Data

Normalized rock quarry and sand and gravel pit data were also prepared for each physiographic region. The information has been both tabulated and plotted as Table 6 and Figure 14, respectively. The data may be used as indicators of: (a) the occurrence of valley train and outwash plain sediments, and (b) the occurrence of carbonate bedrock at relatively shallow depths.

#### Slope Instability

A survey of highway Slope Failures was conducted and analyzed with respect to the physiographic subdivisions; see Table 7. The normalization of failures with respect to subdivision area is a convenient but approximate technique. The Table does indicate however, that the parent materials and other environmental factors are more conducive to slope instability in some subdivisions than in others.

#### Other Aspects of the Generalized Quantification

At this point let us consider the relative uniformity that is exhibited by the various physiographic subdivision with respect to factors considered for generalization.

Table 3  
Tabulation of Normalized Earthwork Quantities  
By Physiographic Regions for Interstate Projects

Physiographic Region	Number of Projects	Average Excavation cyds/mi.	Minimum Excavation cyds/mi.	Maximum Excavation cyds/mi.	Average Special Borrow cyds/mi.	Minimum Special Borrow cyds/mi.	Maximum Special Borrow cyds/mi.	Average Peat Exc. cyds/mi.	Minimum Peat Exc. cyds/mi.	Maximum Peat Exc. cyds/mi.
1) Northern Lake & Moraine Region										
A) Calumet Lacustrine Plain	7	23,000	9,480	31,240	629,340	169,010	2,084,860	189,420	0	917,070
B) Valparaiso Moraine Area	3	91,770	63,890	108,560	122,330	47,790	181,500	18,900	12,540	26,900
C) Kankakee Outwash and Lacustrine Pl.	6	33,540	13,750	45,100	151,360	99,350	246,400	2,660	0	15,770
D) Steuben Moraine Lake Area	9	149,770	78,330	458,440	39,520	0	173,140	25,860	840	93,640
E) Maumee Lacustrine Plain	0	-	-	-	-	-	-	-	-	-
2) Tipton Till Plain	39	97,210	15,060	485,240	107,990	2,570	311,600	1,790	0	21,010
3) Dearborn Upland	5	177,810	41,460	486,900	35,240	5,160	60,180	-	-	-
4) Muscatatuck Regional Slope	5	90,170	56,830	114,470	47,450	50	183,320	0	0	0
5) Scottsburg Lowland	8	118,670	57,650	211,880	76,820	1,070	183,000	0	0	0
6) Norman Upland	2	2,066,420	1,169,010	2,963,830	5,330	0	10,660	0	0	0
7) Mitchell Plain	2	308,630	248,170	319,090	7,810	1,480	16,150	0	0	0
8) Crawford Upland	6	495,720	262,550	698,440	11,270	0	26,110	0	0	0
9) Wabash Lowland	12	162,990	15,700	262,550	92,110	0	396,400	0	0	0

Table 4  
 Tabulation of Normalized Earthwork Quantities  
 By Physiographic Regions for Primary Projects

Physiographic Region	Number of Projects	Average Excavation cysd/mi.	Minimum Excavation cysd/mi.	Maximum Excavation cysd/mi.	Average Special Borrow cysd/mi.	Minimum Special Borrow cysd/mi.	Maximum Special Borrow cysd/mi.	Average Peat Exc. cysd/mi.	Minimum Peat Exc. cysd/mi.	Maximum Peat Exc. cysd/mi.
1) Northern Lake & Moraine Region										
A) Galumet Lacustrine Plain	8	34,020	20,340	51,350	58,430	0	133,730	31,670	3,010	83,290
B) Valparaiso Moraine Area	1	188,830	188,830	188,830	50,740	50,740	50,740	0	0	0
C) Kankakee Outwash and Lacustrine Pl.	4	136,730	25,420	270,360	100,230	20,820	158,660	7,440	0	26,020
D) Steuben Moraine Lake Area	6	65,630	26,550	99,840	36,120	0	101,200	30,640	260	131,690
E) Maumee Lacustrine Plain	0	-	-	-	-	-	-	-	-	-
2) Tipton Till Plain										
1) Tipton Till Plain	17	71,880	13,590	217,130	43,190	0	182,810	4,890	0	38,460
3) Dearborn Upland										
8	64,790	43,570	86,020	37,280	9,820	9,820	65,740	0	0	0
4) Muscatine Regional Slope										
1	204,620	204,620	204,620	12,770	12,770	12,770	12,770	0	0	0
5) Scottsburg Lowland										
0	-	-	-	-	-	-	-	-	-	-
6) Norman Upland										
8	205,100	158,370	307,650	33,680	0	0	46,820	0	0	0
7) Mitchell Plain										
8	359,110	296,880	421,330	8,070	2,670	2,670	13,440	0	0	0
8) Crawford Upland										
0	-	-	-	-	-	-	-	-	-	-
9) Wabash Lowland										
18	41,370	10,050	249,510	140,100	1,720	1,720	605,320	0	0	0



Table 5  
Tabulation of Normalized Earthwork Quantities  
By Physiographic Regions for Secondary Projects

Physiographic Region	Number of Projects	Average Excavation cyds/mi.	Minimum Excavation cyds/mi.	Maximum Excavation cyds/mi.	Average Special Borrow cyds/mi.	Minimum Special Borrow cyds/mi.	Maximum Special Borrow cyds/mi.	Average Peat Exc. cyds/mi.	Minimum Peat Exc. cyds/mi.	Maximum Peat Exc. cyds/mi.
1) Northern Lake & Moraine Region										
A) Calumet Lacustrine Plain	2	149,890	79,200	220,590	224,530	58,820	390,240	155,050	74,800	235,290
B) Valparaiso Moraine Area	0	-	-	-	-	-	-	-	-	-
C) Kankakee Outwash and Lacustrine Pl	0	-	-	-	-	-	-	-	-	-
D) Steuben Moraine Lake Area	2	47,160	34,680	59,630	6,910	0	13,820	32,220	23,290	41,150
E) Maumee Lacustrine Plain	0	-	-	-	-	-	-	-	-	-
2) Tipton Till Plain	9	33,700	7,830	89,110	12,280	0	74,630	70	0	600
3) Dearborn Upland	0	-	-	-	-	-	-	-	-	-
4) Muscatatuck Regional Slope	2	18,740	15,190	22,290	15,080	11,610	18,550	0	0	0
5) Scottsburg Lowland	0	-	-	-	-	-	-	-	-	-
6) Norman Upland	2	167,730	147,270	186,190	23,150	11,380	34,910	0	0	0
7) Mitchell Plain	5	138,470	81,820	226,260	150	0	760	0	0	0
8) Crawford Upland	2	45,310	15,890	74,730	1,590	0	3,190	0	0	0
9) Wabash Lowland	3	36,530	8,670	76,520	21,837	1,800	54,610	0	0	0



# NORMALIZED EARTHWORK QUANTITIES BY PHYSIOGRAPHIC REGIONS FOR INTERSTATE PROJECTS

EXCAVATION - CYDS/MILE

SPECIAL BORROW - CYDS/MILE

PHYSIOGRAPHIC REGION

LEGEND



Average to Maximum



Minimum to Average



Minimum

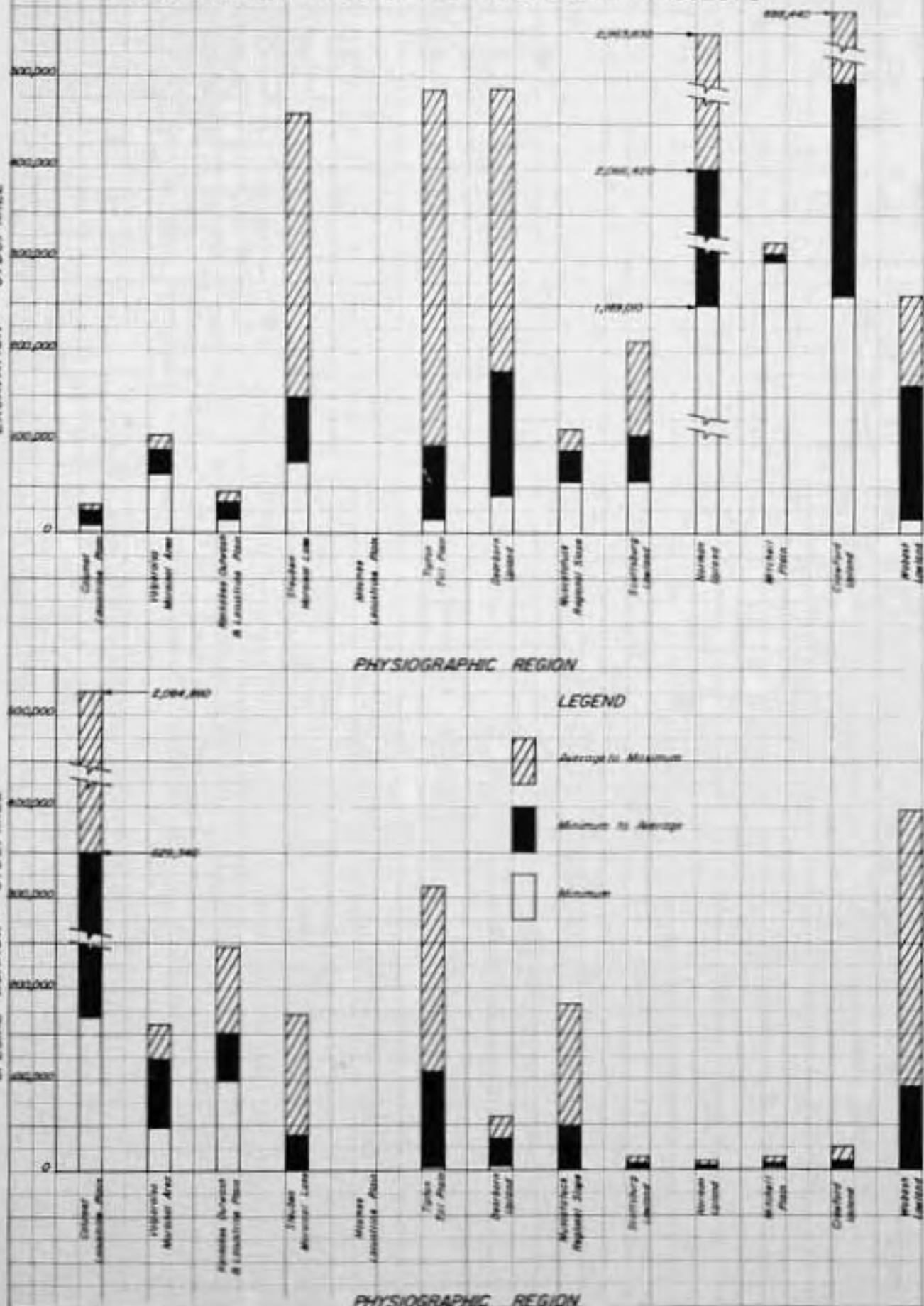


Table 6

## Tabulation of Normalized Rock Quarry and Sand &amp; Gravel Pit Data

Physiographic Region	Approx. Area (sq. mi.)	Number Rock Quarries	Approx. Area (sq. mi.) per Quarry	Number Sand & Gravel Pits	Approx. Area (sq. mi.) per Pit	Sand & Gravel as Percent Physiographic Region
1. Northern Lake and Moraine Region						
A. Calumet Lacustrine Plain	279	0	-	4	70	0
B. Valparaiso Morainal Area	619	0	-	1	619	0
C. Kankakee Outwash and Lacustrine Plain	3256	4	814	19	171	49
D. Steuben Morainal Lake Area	3684	0	-	27	136	31
E. Maumee Lacustrine Plain	146	2	73	1	146	0
2. Tipton Till Plain	13435	27	498	83	162	20
3. Dearborn Upland	1829	3	610	6	305	7
4. Muscatatuck Regional Slope	1653	13	127	2	826	7
5. Scottsburg Lowland	1493	5	299	6	249	21
6. Norman Upland	1233	2	616	1	1233	4
7. Mitchell Plain	1295	12	108	2	647	5
8. Crawford Upland	2432	11	221	3	811	6
9. Wabash Lowland	4937	3	1646	17	290	23

# Normalized Rock Quarry And Sand & Gravel Pit Data

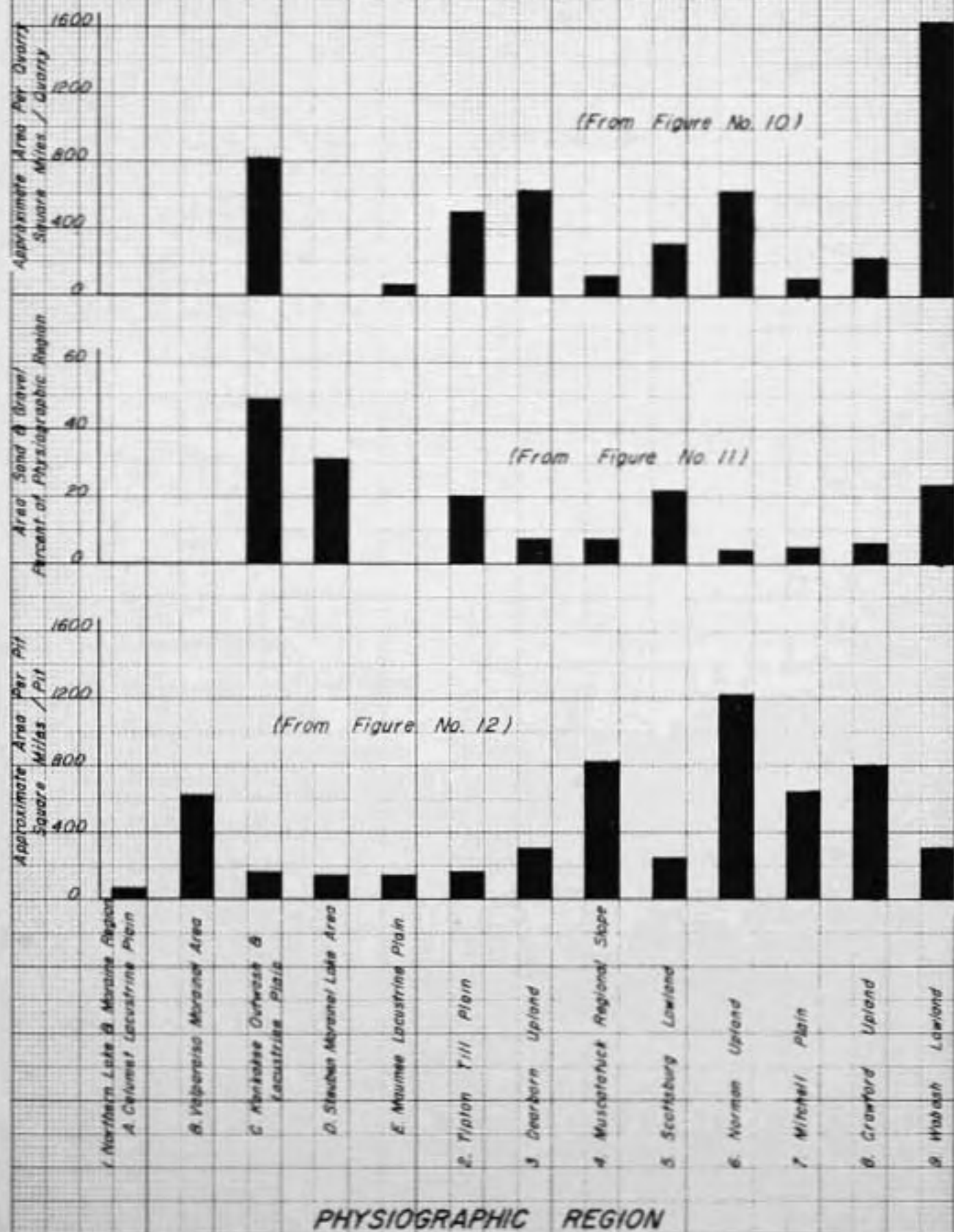


Figure 14

Table 7  
Summary of Slope Failures per Physiographic Region

Physiographic Region	Number of Failures	Normalization (sq. mi.) per Failure
1. Northern Lake and Moraine Region		
A. Calumet Lacustrine Plain	0	-
B. Valparaiso Morainal Area	1	619
C. Kankakee Outwash and Lacustrine Plain	0	-
D. Steuben Morainal Lake Area	2	1,842
E. Maumee Lacustrine Plain	0	-
2. Tipton Till Plain	1	13,435
3. Dearborn Upland	16	114
4. Muscatatuck Regional Slope	0	-
5. Scottsburg Lowland	4	373
6. Norman Upland	2	617
7. Mitchell Plain	2	647
8. Crawford Upland	10	243
9. Wabash Lowland	3	1,646
Total	41	

The relative percentages of significant soil parent material areas in the physiographic regions can be viewed as a first measure of uniformity. The logic of this premise can be illustrated by the following example. Refer to the two upper bar graphs of Figures C-1 through C-13 shown in Appendix C , and consider the circumstance of a small number of significant soil parent material areas or landforms in a physiographic region. "Significant" areas are those comprising more than five percent (5%) of the total physiographic region. Where the relative percentages are high, only a few soil parent material areas are present and these are presumedly repeating in a common or dominant pattern. Such a situation is viewed as a relatively uniform one. Such a first approximation of uniformity is shown in Table 8 where four general ratings have been established as follows: (I - Very Uniform) has one to two significant landforms, (II - Uniform) two to three significant landforms, (III - Slightly Uniform) has three to four significant landforms, and (IV - Complex) has four to five significant landforms.

A second degree of measure of uniformity within a physiographic region involves the soil series associations encountered within the soil parent material areas or landforms. Consider the lower bar graphs of Appendix C , Figure C-1 to C-13. A small number of significant associations within a soil parent material area is interpreted to mean a high degree of uniformity. Further discussion, amplification and reinforcement of this second degree of uniformity is contained under the heading "Specific Quantification of Significant Factors Influencing a Regional Approach to Highway Soils Considerations."

Table 8

Ratings for First Degree of Uniformity for Soil Parent  
Material Areas Within Each Physiographic Region

Physiographic Region	Rating
1. Northern Lake and Moraine Region	
A. Calumet Lacustrine Plain	II
B. Valparaiso Morainal Area	I - II
C. Kankakee Outwash and Lacustrine Plain	IV
D. Steuben Morainal Lake Area	III
E. Maumee Lacustrine Plain	I
2. Tipton Till Plain	II - III
3. Dearborn Upland	III - IV
4. Muscatatuck Regional Slope	III
5. Scottsburg Lowland	IV
6. Norman Upland	III - IV
7. Mitchell Plain	III
8. Crawford Upland	II - III
9. Wabash Lowland	IV

General Definition of Ratings:

- I - Very Uniform
- II - Uniform
- III - Slightly Uniform
- IV - Complex



### Terrain Elevation Interval vs. Percent Area Physiographic Region

The method for obtaining these data and plotting these frequency distribution curves was discussed previously. The curves (included in Appendix B) were grouped into three types.

Type 1. A high peak or mean value for Percent Area Physiographic Region and a narrow range for Terrain Elevation Interval characterize this group. Slight local relief and minor topographic expression are generally implied, i.e., almost level to gently undulating terrain.

Type 2. Such curves have a moderate to high peak or mean value for Percent Area Physiographic Region and a moderate to wide range for Terrain Elevation Interval. Moderate variations in local relief and moderate topographic expression, viz., gently undulating to rolling terrain are indicated.

Type 3. A small to moderate peak or mean value for Percent Area Physiographic Region and a wide range for Terrain Elevation Interval characterizes these curves. Large variations in local relief and major topographic expression are implied, i.e., rolling to rough terrain.

A tabulation of the Terrain Elevation Interval Curve Types for each physiographic region has been included in Table 9.

### Drift Depth Interval vs. Percent Area Physiographic Region

Again, the method employed for plotting these frequency distribution curves was discussed previously. The curves (included in Appendix B) were of two types.

Type 1. These curves showed an approximate normal distribution, with low percentages for extreme values and a peak at about the distribution mean. Such curves generally indicate the bedrock is well covered

Table 9

Summary of Terrain and Drift Depth Quantification Factors

Terrain Elevation Interval      Drift Depth Interval      <sup>\*\*</sup> Interstate Highway Earthwork Factor, E(%)

Physiographic Region	Curve Type	Curve Type	Earthwork Factor, E(%)
1. Northern Lake and Moraine Region			
A. Calumet Lacustrine Plain	1	1	96
B. Valparaiso Morainal Area	2	1	57
C. Kankakee Outwash and Lacustrine Plain	1	2	81
D. Steuben Morainal Lake Area	2	1	21
E. Maumee Lacustrine Plain	1	2	***
2. Tipton Till Plain	2	2	55
3. Dearborn Upland	3	2	16
4. Muscatatuck Regional Slope	3	2	35
5. Scottsburg Lowland	2	2	7
6. Norman Upland	3	*	1
7. Mitchell Plain	2	*	3
8. Crawford Upland	3	*	2
9. Wabash Lowland	2	*	36

\* Indicates areas are south of the Wisconsin Glacial Boundary

<sup>\*\*</sup> Earthwork Factor, E(%) =  $\frac{\text{Normalized Special Borrow}}{\text{Normalized Total Earthwork}} \times 100$

=  $\frac{\text{Special Borrow Per Mile}}{\text{Special Borrow Per Mile} + \text{Excavation Per Mile}} \times 100$

It should be noted that the percentages shown above are for interstate highway projects. The same procedure can be followed for primary and secondary highway projects.

\*\*\* Data not readily available.

and will be encountered infrequently in an average project.

Type 2. These distributions are skewed to the left, i.e., the curve peaks near the left extreme instead of near the mean value. Since the left extreme is the Drift Depth Interval of 0 to 50 ft., bedrock may be encountered more than occasionally on an average project. The probability of encountering bedrock on a project is dependent upon the actual percentage for the 0 to 50 ft. interval and to a lesser extent on the percentage for the 50 to 100 interval.

As mentioned previously, this information was compiled from Wayne's (72) "Map Showing Thickness of Drift in Indiana North of the Wisconsin Glacial Boundary". For these regions where distribution curves for the total physiographic region are not available, supplemental data are included later under the heading "An Approach to Specific Quantification of Significant Factors Influencing a Regional Approach to Highway Soils Considerations".

A tabulation of the Drift Depth Interval Curve Types for each physiographic region has been included in Table 9.

#### Normalized Earthwork Quantities by Physiographic Regions

The normalized earthwork quantities by physiographic region has been included in Tables 3, 4 and 5 for Interstate, Primary and Secondary projects, respectively. These data constitute useful descriptors of the terrain in which the projects were constructed. A further amplification of this point is shown in Table 9. An "Earthwork Factor" was defined as:

$$\text{Earthwork Factor, } E(\%) = \frac{\text{Normalized Special Borrow}}{\text{Normalized Total Earthwork}} (100)$$

$$= \frac{\text{Special Borrow Per Mile}}{\text{Special Borrow Per Mile} + \text{Excavation Per Mile}}$$

This factor was calculated for the Interstate projects only. The lower the factor, the rougher the terrain.

Normalized peat excavation quantities have also been included in Tables 3, 4 and 5. These data indicate the relative concentration of peat, marl and muck areas within the State.

#### Interpretation of Generalized Quantification within Physiographic Regions

The results of the generalized quantitative investigations have been summarized and interpreted for each physiographic region.

##### Northern Lake and Moraine Region

Calumet Lacustrine Plain. The surficial soils in this subdivision consist primarily of dune sand, shown as approximately 66% on the engineering soils map graph in Figure C-1. Lakebed sediments, Wisconsin till and end moraines are other significant parent material areas, each amounting to more than 5% of the total area. Lake sediments comprise approximately 86% of the total area according to the glacial geology mapping, see Figure C-1, and dune sand comprises the remaining 14%. The lacustrine deposits of Glacial Lake Chicago were subsequently covered by the dune sand indicated on the engineering soils map and the agricultural soils map. According to Table 8, a rating of II (Uniform) has been suggested for this region. Figure C-1 shows that water assorted sands and gravels of Wisconsin glacial origin cover approximately 68% of the total area; soils 1, 3 and 39 account for 29%, 19% and 20%, respectively. Other significant soil coverages are soil 39, which is a Wisconsin lakebed deposit, comprising about 10%, and soils 28 and 29, fine textured Wisconsin tills, accounting for 5% and 8%, respectively.

As shown in Figure B-1, the Terrain Elevation Interval and the Drift Depth Interval relations are Type 2. This indicates almost level to gently undulating topography in which bedrock will not likely be encountered, even in cuts.

The normalized earthwork data (Tables 3, 4 and 5), the normalized quarry and sand and gravel pit data (Table 6), and the Summary of Terrain and Drift Quantification Factors (Table 9), verify that the terrain is almost level, requiring little cut excavation and larger amounts of special borrow. They also reinforce the conclusion that bedrock is not a major engineering consideration, since rock quarrying is non-existent. Tables 3, 4, 5 and 9 indicate that special borrow predominates on projects within this region. The Earthwork Factor in Table 9 is 96%.

An examination of county engineering soils maps and reference to Tables 3, 4 and 5 reveal that numerous areas of peat, marl and muck of Recent Age are present at the surface and are in some cases buried. These very poor soils can occur in any depression or channel, and constitute one of the major engineering problems of this region. Settlement of the lacustrine soils underlying the dune sand constitutes another major engineering consideration for relatively high embankments, bridge structure foundations and approaches to the structures. Further discussion of these and other engineering soils considerations occurs later under the heading, "Specific Quantification of Significant Factors Influencing a Regional Approach to Highway Soils Considerations".

The data presented in Table 7 indicate that the physiographic region is not one of high landslide susceptibility. Such a statement tacitly assumes that peat, marl and/or muck deposits will be identified and properly treated prior to building any embankment.

Valparaiso Morainal Area. Soils in this physiographic region are primarily of glacial origin from the Wisconsin stage. The engineering soils map shows approximately 75% end moraine and 22% Wisconsin till. Recent deposits of peat, marl and muck are found in some depressions however, their occurrence is infrequent, as are the lacustrine and alluvial deposits.

The glacial geology map shows essentially the same data as above with end moraine comprising approximately 83% and ground moraine about 12% of the total. This area of gently undulating terrain represents the terminus of the Lake Michigan Lobe of the Cary Substage, and a First Degree Uniformity Rating of I (Very Uniform) to II (Uniform) is shown in Table 8.

Pedological soils predominating in this area are of Wisconsin drift extraction. They have various textures, generally fine or medium. The main soil numbers are 61, 44 and 29 for which percentages of about 28, 27 and 24, respectively, were obtained. Soil numbers 49 and 7 were of lesser significance having 7% and 5%, respectively.

The Terrain Elevation Interval and Drift Depth Interval curves are of Type 2 and Type 1, respectively. This represents gently undulating to rolling terrain, and indicates that bedrock will not likely be encountered on an average highway project.

The other data included in Tables 3, 4, 5, 6 and 9 tend to verify the above conclusions. Namely, the topography is gently undulating to rolling, so that excavation does not predominate; that bedrock will probably not be encountered even in cuts on an average project; that sand and gravel is virtually non-existent; and that the Earthwork Factor



of 57% indicates an almost equal amount of excavation and special borrow on Interstate projects.

Table 7 seems to indicate that slope failures are not prevalent in this physiographic region. The one reported instability occurred within an embankment, not in the in-situ soils. However, if peat, marl and/or muck is encountered as a foundation, some care is required to prevent instability.

Kankakee Outwash and Lacustrine Plain. The deposits in this physiographic region are primarily of glacial origin, consisting of outwash and lacustrine sediments. Outwash materials reworked by wind form sand dunes. The predominant parent material areas shown on the engineering soil maps are porous substrata 18%, sands 49%, Wisconsin till 17%, sand-gravel-till 5%, and muck-peat-marly soils 17%.

A slightly different picture is shown by the glacial geology mapping. The area is comprised of lake sediments 16%, dune sand 35%, valley train and outwash plain sediments 40% and Wisconsin ground moraine 7%. The outlines of the broad valley train and outwash plain areas are in part genetically related to the present St. Joseph, Kankakee, Tippecanoe and Iroquois Rivers. The First Degree Uniformity Rating of IV (Complex), shown in Table 8, seems appropriate. The pedologic soils mapping shows 59% of the area to be sand and gravel from Wisconsin glaciation. The soil numbers are 1, 45, 3 and 43 covering 35%, 5%, 12% and 17%, respectively. Wisconsin lakebed sediments comprise about 9% of the area as soil number 4. The significant soils are 41 and 30 having 7% and 8%, respectively. They are derived from Wisconsin drift of various textures.

Terrain Elevation Interval data show a Type 1 curve, and that a

Type 2 curve applies for the Drift Depth Interval Data. This indicates an almost level to gently undulating terrain in which rock may be encountered on an average project, depending upon the actual percentages for the 0 to 50 ft. and 50 to 100 ft. intervals. The drift depth curve shows 18% for the former and 24% for the latter. The combined information indicates bedrock will not likely be encountered in cuts, but that rock may be encountered at some structure locations, depending upon the depth of the foundation. The generalization of almost level to gently undulating terrain is reinforced by the data of Tables 3, 4 and 5. Table 6 projects an abundance of sand and gravel and a limited occurrence of bedrock at shallow depths. The major engineering problems are associated with the recent alluvium, lakebed sediments and the muck-peat-marl depression deposits. The data of Table 7 indicate that instabilities can be controlled by due recognition and proper treatment of these potential foundation materials. The Earthwork Factor for Interstate projects is 81%, emphasizing the need for special borrow. It can also be seen from an examination of Table 4 that a different conclusion could be reached. This discrepancy may result from the differences in the standards for Interstate and Primary projects, and may possibly be due to the particular locations of projects within each class of highway in the physiographic region.

Steuben Morainal Lake Area. This physiographic sub-section is more complex in its geomorphic history and topographic expression than any other area in the Northern Lake and Moraine Region. In some locations, the terrain is almost as rugged as in the bedrock uplands of southern Indiana, with local relief exceeding 200 ft. The engineering soils map

indicates that the porous substrata parent material area accounts for 21% of the total with young drift 22%, end moraines 50%, and areas of sand-gravel-till 5%. Many peat and marl deposits are present, but due to scaling limitations are not mapped. Generally, they occur in depressions and in areas presently occupied by lakes, being buried at many locations under a cover of glacial drift eroded from the surrounding higher ground. These statements are verified from the peat excavation information included in Tables 3, 4 and 5.

Similar conditions are indicated by the glacial geology map which shows valley train and outwash plain sediments to comprise 20% of the total region area, along with end moraine (44%) and Wisconsin ground moraine (39%). The end moraines are terminal moraines of the Saginaw ice Lobe, and the northern limits of the Erie Lobe. The data in Table 8 show a First Degree Uniformity Rating of III (Slightly Uniform) for this physiographic region.

The agricultural soils map indicates the surficial soils in this region are the result of Wisconsin glaciation. Assorted water deposited sand and gravel makes up 16% of the total area. This is soil type number 31. Medium textured till and sandy drift accounts for at least 55% of the region area, with soil type numbers 33, 30, 10, 8 and 49, having percentages of 25, 11, 7, 7 and 5, respectively. Soil type numbers 7, 28, and 29 having 5%, 6%, and 9% respectively, are Wisconsin till of fine to medium textures.

The Terrain Elevation Interval curve has the Type 2 characteristics and the Drift Depth Interval conforms quite well to the Type 1 curve. These curves indicate gently undulating to rolling terrain and it is not likely that bedrock will be encountered on the average highway project.

The other data included in Tables 3, 4, 5, 6 and 9 tend to confirm the above conclusions. The rougher terrain necessarily results in more cuts and excavation on highway projects and less special borrow. Sand and gravel pits are in abundance in this region, but rock quarries are non-existent. The Earthwork Factor of 215 indicates that excavation predominates on Interstate highway projects. An examination of Tables 3, 4 and 5 also verifies this conclusion.

This physiographic region is generally not considered to be landslide susceptible. The data of Table 7 report 2 slides in this region. Their cause has been ascribed to peat and/or marl foundation soils which were incompletely removed during the process of treating the deposit, and which resulted in embankment failures.

Maumee Lacustrine Plain. The Maumee Lacustrine Plain physiographic region in Indiana represents the small most western part of the abandoned floor of glacial Lake Maumee, which once occupied the Lake Erie basin in late Pleistocene times. The soil parent material areas in this region are the most uniform in the entire state. Data from the engineering soils map indicated 90% of the area is covered by the lakebed deposits, with recent alluvium comprising approximately 7%. This is the primary reason for Table 8 showing a First Degree Uniformity Rating of I (Very Uniform).

Glacial geology data show lake sediments over 91% of the total physiographic region. Ground moraine resulting from Wisconsin glaciation is the only other relatively significant parent material, accounting for 5% of the total.

As would be expected, the agricultural soils data give similar results. Wisconsin lakebed deposits comprise at least 93% of the total area.

Soil type numbers 48 and 58 have 65% and 28%, respectively, of the total area.

Curves for the Terrain Elevation Interval and the Drift Depth Interval conform to Type 1 and Type 2, respectively, having the characteristics previously mentioned. The Terrain Elevation Interval curve is the best example of almost level topography in this entire study. The straight vertical line indicates that the entire area is in a single elevation interval. From the Drift Depth Interval curve, it is probable that bedrock will be encountered on an average highway project, probably for the structure foundations.

Lakebed and alluvial deposits afford some of the more challenging highway soils problems. Table 6 confirms the conclusions that although sand and gravel deposits are negligible, bedrock quarries do exist at commercial depths. Therefore, one can expect to encounter rock frequently in highway work in this area. The Drift Depth Interval data show for Intervals 0 to 50 and 50 to 100, area percentages of 40 and 52, respectively, verifying this conclusion.

Slope instability does not appear to be a major consideration in this area, due in part to the topography and to the absence of high highway embankments.

An earthwork factor was not calculated for this region. Data for Indiana highway projects were not readily available.

#### Tipton Till Plain

The nearly flat to gently rolling topography of this physiographic region is sometimes considered to be the most typical of the Indiana landscape. Since the area is so large, the extremes vary from almost

level over a large portion to something approaching a rolling appearance near the boundaries to the south, west and northeast. The primary parent soil areas are of Wisconsin glacial origin. They consist of porous substrata (5%), recent alluvium (7%), young till (63%) and end moraines (23%). A limited amount of peat and unstable soil areas occur infrequently in this subdivision.

Glacial geology data show that ground moraine occupies a majority (60%) of the area of this physiographic region. The other main parent material areas are valley train and outwash plain sediments (17%) and end moraine (21%). The end moraine deposits are poorly developed, having flat slopes and limited local relief. A First Degree Uniformity Rating of II (Uniform) to III (Slightly Uniform) as shown in Table 8, seems to be appropriate.

Data from the agricultural soils map indicate that Wisconsin till comprises a major part of this region. Soil type numbers 6, 9, 7, 28, 29, 11 and 13 are the predominant agricultural soil areas encountered. They account for 5%, 23%, 13%, 17%, 10%, 10%, and 8%, respectively. The till is overlain intermittently by a loess cover in the area of Soil type numbers 11 and 13.

A Type 2 curve characterizes the Terrain Elevation Interval data for this area, and for the Drift Depth Interval, a Type 1 curve is appropriate. This typifies an almost level to gently undulating to gently rolling topography and indicates that bedrock will not likely be encountered on an average highway project in this subdivision. However, due to the vast area covered by this region, rock can be expected to occur in cuts in scattered areas of limited extent. Bedrock can be expected to



occur regularly in the border areas to the west, northeast and along much of the southern boundary of this physiographic region. Tables 3, 4, 5, 6 and 9 indicate that rock outcrops and quarries are encountered in certain limited areas, that sand and gravel pits are numerous (due to the valley train and glacial outwash deposits), and that the gently undulating to rolling terrain leads to more cuts and excavation and less special borrow. An earthwork factor of 55% was obtained for the Interstate highway projects considered, as shown in Table 9. This indicates slightly more special borrow than excavation. The data of Table 4 and 5 show the reverse, because of the variation in standards and design procedures for the given classes of highways.

Peat excavation is a factor based on the data shown in Tables 3, 4 and 5, however, these deposits do not occur frequently enough to produce a significant regional problem.

As shown in Table 7, the writer is aware of only one case of slope instability within this region. It developed in an embankment due to poor foundation soils in an alluvial plain deposit. Additional instabilities would probably develop if unstable foundation soils such as peat, marl and/or muck were not properly identified and treated.

#### Dearborn Upland

The surficial soils of this area consist primarily of glacial drift of Wisconsin Age in the northern third and Illinoian Age over most of the remainder. These soils are underlain by virtually flat lying limestones and shales of late Ordovician Age that outcrop along the crest of the Cincinnati Arch. The engineering soils data indicate young Wisconsin till comprises 17%, end moraines 8%, old Illinoian drift 37%, and

Interbedded Shale and Limestone 32%.

The glacial geology data indicate that the old drift of Illinoian age predominates, occupying 62% of the total area. Wisconsin till covers 22% of the area, and valley train and outwash plain sediments 8%, with end moraine accounting for 5%. The data in Table 8 indicate a First Degree Uniformity Rating of III (Slightly Uniform) to IV (Complex) for this physiographic unit.

The agricultural soils map shows that Wisconsin till, overlain occasionally with a thin loess mantle, covers at least 25% of the region. Soil type numbers 11 and 13 account for 19% and 6%, respectively. The Illinoian drift covers about 32% of the area, with Soil type numbers 60, 16 and 53 accounting for 16%, 9% and 7%, respectively. Approximately 31% of the region is residual soil derived from the limestone and limey shale of the Ordovician System. Soil type numbers 17 and 50 make up 22% and 9% of the area, respectively.

The Terrain Elevation Interval curve is of Type 3, and the Drift Depth Interval has the characteristics of a Type 2 curve. This indicates undulating to rolling topography and a frequent occurrence of bedrock at relatively shallow depths. It should be emphasized that the Drift Depth Interval curve represents only that portion of the physiographic region north of the Wisconsin glacial boundary, or about 30 percent of the total area. Therefore, the interval percentages of 38 and 36 for the 0 to 50 and 50 to 100 intervals are for only that part of the region. The supplemental information for Interstate projects, was limited, however, information for primary and secondary projects indicates bedrock is frequently encountered in upland cuts. The rock quarry data

shown in Table 6 and Figure 14 tend to confirm this conclusion, even though good quality bedrock is not plentiful in this area. The data shown in Tables 3, 4 and 5 indicate undulating to rolling terrain does indeed exist because of the large quantities of excavation and minor amounts of special borrow. An earthwork factor of 16% is shown in Table 8 which also confirms the above conclusion.

Peat excavation does not seem to be a consideration in this physiographic unit as shown by the data in Tables 3, 4 and 5. This is probably true of most areas where residual soils and soils from the older glacial stages predominate. An indication of this is also evident in Table 10, which was previously presented in Witzak (74). The above statements do not preclude the possibility of encountering localized organic accumulations in depressions.

The natural slopes in this area are usually relatively gentle, possibly indicating the excessive weathering characteristics and limited shear strength of the underlying parent materials. These indicators are reinforced by the data shown in Table 7. A total of 16 slope failures have come to the attention of the writer, which makes this the most landslide susceptible area in the entire State. Fourteen of these instabilities were associated with the residual soils of the area, with natural slopes, embankments and cuts accounting for 11, 1 and 2, respectively. The other two instabilities involved embankments placed on lacustrine and alluvial sediments in flood plains. Most of the failures are confined to about the southern one third of this physiographic unit, which is primarily the residual soil area.

TABLE 10 SUMMARY COMPARISON OF GLACIAL TERRAINS IN THE  
CENTRAL PORTION OF THE CENTRAL AND EASTERN LOWLAND PROVINCE

Glacial Stages or Substages	Predominant Physiographic Section of Occurrence	Degree of Dissection	Relative Abundance of Features (see Code)						
			Conspicuous End Moraines	Till Plains	Outwash Plains	Lakes	Organic Areas	Lacustrine Plains	Aeolian Deposits
Kansan	Dissected Loessial and Till Plain (11i)	A	C-D	B-C	C-D	C-D	C-D	C-D	A-B
Illinoian	Central Till Plain (11f)	B	C-D	B-C	B-C	C-D	C-D	C-D	A-B
Tazewell and older Wisconsin	Central Till Plain (11f)	C	C	A-B	B-C	B-C	B-C	B-C	A-B
Cary and Younger Wisconsin	Eastern Lakes and Lacustrine (11e), and Western Lakes and Lacustrine (11h)	D	A-B	C-D	A-B	A	A-B	A-B	D

Code: Heavy (A)  
Medium (B)  
Light (C)  
Lacking (D)

AFTER WITCZAK (74)

### Muscatatuck Regional Slope

Unconsolidated deposits in this region consist primarily of glacial drift, Wisconsin Age in the northern 41% and Illinoian Age over most of the remainder. These soils are underlain predominantly by limestone and dolomite of the Silurian System, but a considerable amount of bedrock from the Devonian System and minor amounts for the Ordovician System are also present. The dip of the bedrock formation is about 20 feet per mile which is slightly greater than the 12 feet per mile slope of the bedrock surface. The slope directions correspond quite well, and one can conclude that the regional slope of the bedrock surface is structurally controlled. The engineering soil parent material map indicates Old Illinoian drift comprises 61% of this physiographic region. Young Wisconsin till accounts for 24% and end moraines make up 11% of the area.

The glacial geology map shows Illinoian drift predominating with 53%, Wisconsin ground moraine accounts for 28%, valley train and outwash plain sediments (9%), and end moraine (9%) of the total area. A First Degree Uniformity Rating of III (Slightly Uniform) is shown in Table 8.

Agricultural soils information indicates soils derived from Illinoian till make up at least 55% of the total region. In places, this till is covered with a thin loess mantle. Soil type numbers 60, 16, 51 and 53 cover 12%, 21%, 6% and 16% of the total area, respectively. Wisconsin till with a thin loess cover in places accounts for at least 37% of the total area. This is comprised of Soil type numbers 9, 11 and 13 having percentages of 7%, 19% and 11%, respectively.

The Terrain Elevation Interval data conform to the Type 3 curve. Drift Depth Interval data clearly conform to the Type 2 curve. This

information tends to verify that the terrain is undulating to gently rolling and that bedrock is likely to be encountered on some of the projects within the limit of the Wisconsin glacial boundary. The area within this limit amounts to approximately 41% of the total and this is the area used in compiling the values for the Drift Depth Interval curve, which indicates 58% in the 0 to 50 interval and 27% in the 50 to 100 interval. Verification of this conclusion is provided in Table 6 and Figure 14 by the number of rock quarries. Sand and gravel pits are a rarity. The average amount of excavation is more than the average special borrow quantity for projects within this physiographic unit, as indicated in Tables 3, 4 and 5. An earthwork factor of 35% is shown in Table 9 for Interstate highways, possibly indicating milder topographic expression than in the Dearborn Upland to the east. Peat excavation is not a major consideration in this area, as verified by Tables 3, 4 and 5.

According to the data available to the writer (Table 7), there have been no highway-associated landslides in the region. This is consistent with the notion that the bedrock in this area is of a more resistant nature than that encountered in the Dearborn Upland.

#### Scottsburg Lowland

The soils in this region have been formed in a strongly asymmetric trough, following the outcrop belt of relatively non-resistant shales of late Devonian and early Mississippian age. Engineering soil parent material are primarily Old Illinoian till (53%), lakebeds (12%), recent alluvium (11%), sandstone with some shale residual (10%), and sands (5%).

Glacial geology data tend to confirm the above, however, the manner of definition of areas may lead to some confusion. The areas described



as lakebed and alluvium on the engineering soil parent material map are approximately the same areas shown as valley train and outwash plain sediments on the glacial geology map. These sediments account for about 29%, with the remainder of the area being Illinoian drift (49%), dune sand (7%), and bedrock or residual soil (7%). The data in Table 8 indicate a First Degree Uniformity Rating of IV (Complex).

From the agricultural soils map, it was determined that soils derived from Illinoian till amount to at least 37% of the total area. Soil type numbers 60, 16 and 51 make up 12%, 10% and 15% of the total area, respectively. A thin loess mantle covers these soils in places. Soil type number 31 is derived from assorted water deposited sand and gravel of Wisconsin age and it accounts for 7% of the total area. Wisconsin till amounts to 6% of the total area and is shown as Soil type number 9. Values of 10% and 11% were obtained for soil type numbers 12 and 55, respectively, which are formed from stream bottom materials, and sand and gravel terraces. Residual sandstone and shale with a thin loess cover in places make up about 7% of the total physiographic region.

Terrain Elevation Interval and Drift Depth Interval data are both characterized quite well by Type 2 curves. The former curve seems to indicate gently undulating to gently rolling terrain. The latter curve predicts an encounter with bedrock on some highway projects, since the intervals 0 to 50 and 50 to 100 had percentages of 34 and 36, respectively. These bedrock data have limited value, since the area north of the Wisconsin glacial boundary represents only 8% of the total. However, when these data are combined with the information given in Table 6 and Figure 14 the conclusion is verified. Rock quarries do exist and would

probably be more abundant if the bedrock was of a better nature and quality. Most of the consolidated formations within this region are shales, occasionally with interbedded sandstone. Sand and gravel pits are present, but not abundant. The data in Tables 3, 4 and 5 indicate topography as previously described, since cuts or excavation predominate over special borrow. This is also substantiated by the data presented in Table 9, which show an earthwork factor of only 7% for Interstate highway projects. Peat excavation is not a major consideration.

This physiographic region is considered to have moderate landslide susceptibility, with a total of four failures shown in Table 7. One instability was for a cut in residual soils, and another was for an embankment built on residual soils. A cut in a lacustrine deposit produced the third and an instability within an embankment accounts for the fourth. Most of the failures were confined to the southern portion of this physiographic unit.

#### Norman Upland

Probably the best visual boundary between any of the physiographic subdivisions is the Knobstone Escarpment, dividing the Scottsburg Lowland to the east and the Norman Upland to the west. Its crest is, in places, 400 to 600 feet above the lowland valleys to the east. This upland is formed by relatively resistant sandstones and siltstones interbedded with softer shales of the Borden Group of the early to middle Mississippian System. In the north-central part of the upland, middle Mississippian limestone is encountered. All of the bedrock dips about 25 feet per mile to the west-southwest. More soluble younger limestones occur along the poorly defined western boundary of the uplands.

Engineering soils data indicate that residual soils predominate. Limestone residuals constitute 25% of the total area, sandstone with some shale residuals account for 35%, and interbedded limestone and shale capped with a thin mantle of Illinoian till make up about 6% of the physiographic region. Lakebed soils comprise about 13% of the area and Old Illinoian till accounts for 15%.

The glacial geology data also show residual soils predominating, covering 54% of the total area. Illinoian till accounts for 33% of the area and the valley train and outwash plain sediments make up 8%. A First Degree Uniformity Rating of III (Slightly Uniform) to IV (Complex) is shown in Table 8.

As indicated by the agricultural soils map, soil type number 18, derived from residual sandstone and shale capped in places with a thin loess cover comprises 46% of the area. Soil type numbers 22 and 23 account for 14% and 9% of the physiographic region, respectively. Illinoian till with an occasional loess cover comprises 11% of the total area as Soil type number 14, with stream bottom and sand and gravel terraces, shown as soil type number 55, accounting for a percentage of 8.

The curve characterizing the Terrain Elevation Interval conforms to the Type 3 shape. Drift Depth Interval data are limited in value since only about 2% of the total area is glaciated. The curve has the Type 2 characteristics, with intervals of 0 to 50 and 50 to 100 showing 69% and 28% respectively. These data tend to reflect the undulating to rolling topography of the area, and to show that bedrock is likely to be encountered on some highway projects. Quarries are not plentiful, probably because of the nature of the bedrock, and sand and gravel pits are almost

non-existent. The data in Tables 3, 4 and 5 tend to confirm the above conclusions, in that rock cuts occur frequently on the projects involved, and the ratio of cuts or excavation to special borrow is very high. This result is greatly affected by one factor, viz., if the project traverses the Knobstone Escarpment, very large quantities of excavation can be expected in an attempt to maintain a reasonable grade.

The main considerations of interest to the soils engineer in this region are the residual soils, which possess some undesirable properties, and the existence of sinkholes in the soluble limestone near the western boundary of the region. As mentioned previously, peat excavation is not a significant consideration in residual soil areas. This is confirmed by the data in Tables 3, 4 and 5.

The lowest earthwork factor computed for any physiographic region studied based on Interstate highway projects was obtained for this area. The value of only 15 indicates almost no special borrow was required. This conclusion was also substantiated by the data presented in Tables 4 and 5.

Slope failures do not appear to be encountered with any frequency within this region, based on the data presented in Table 7. Two instabilities are reported and both occurred in cuts made in residual soil and shale areas in the southern portion of this physiographic unit. Therefore, the area is given a landslide susceptibility rating of minor.

#### Mitchell Plain

The engineering soil parent material map shows the surficial soils in this physiographic region to consist primarily of residual limestone deposits. They account for at least 52% of the total area. Old

(Illinoian) drift over limestone comprises 28% of the area and Old till, the other predominate soil parent material, accounts for 14%. The soils are underlain by limestones from various formations and of varying quality. The famous Indiana Limestone used for building purposes throughout the country comes from the Salem Limestone quarried in the Bloomington-Bedford area. More soluble limestone of the younger St. Louis and St. Genevieve formations underlies much of the area.

Residual soils are shown over at least 73% of the total area by the glacial geology map. The predominate glacial areas are lacustrine (6%), valley train and outwash plain sediments (7%) and Old (Illinoian) till (14%). Table 8 data indicate that a First Degree Uniformity Rating of III (Slightly Uniform) is applicable.

The data from the agricultural soils map verify the conclusion drawn above. Soil type numbers 22, 57 and 23, derived from limestone bedrock having a thin loess cover in places, comprises 51%, 17%, and 8% of the total area, respectively. Residual limestone and limey shale accounts for 5% of the total area and is shown as soil type number 59 on the map. Illinoian till, with a thin loess cover in places, shown as soil type number 15, makes up 12% of the area.

A Type 2 curve seems to adequately characterize the data for the Terrain Elevation Interval. The southern boundary of Wisconsin glaciation actually forms the northern boundary of this physiographic region and the two regions to the west. Therefore, the Drift Depth Interval data are not available for these three physiographic regions. All of the above conclusions are strengthened by the data included in Tables 3, 4, 5 and 6. Rock cuts are frequent in occurrence, and quarries are

plentiful, indicating that sufficient quantities of good quality bed-rock are available, and further that they will likely be encountered on some highway projects. The existence of poor quality solutioned limestone is evident from the caves and caverns which are known to exist in these formations, and from the high density of sinkholes occurring throughout this physiographic region, indicating subterranean drainage. As one would expect, excavation predominates over special borrow in this region. Important soils engineering problems are similar to those outlined for the Norman Upland, except the sinkhole occurrence density is much greater in this region, and the residual soils have some of the poorest physical properties of any encountered in the entire State. Peat excavation in this primarily residual soil area is not a significant consideration. An earthwork factor of 3½ is shown in Table 9 for Interstate highways, verifying the above conclusion that excavation predominates over special borrow.

This area has been given a landslide-potential rating of minor, since only two failures are recorded. They were both for embankments placed on lacustrine deposits, where the shear failure developed because of the unstable foundation soils.

#### Crawford Upland

Unconsolidated deposits within this physiographic region are underlain by alternating sandstones, shales and limestone of the Chester Series of the upper Mississippian System in the eastern section, and interbedded sandstones and shales from the Mansfield Formation of the Pottsville Series and Pennsylvanian System in the western portion. The eastern part of this subdivision is characterized by numerous springs



and by many of Indiana's most famous caverns (including Wyandotte and Marengo Caves) formed in the soluble middle Mississippian limestones beneath protective Chester or Mansfield caprocks. Some of the most rugged topography in Indiana is found in this region; local relief on the order of 300 feet to 350 feet occurs. The engineering soils data indicate that residuals from limestone, sandstone and shale comprises about 64% of the total area. Old (Illinoian) till accounts for 21% of the subdivision, and lacustrine deposits make up 9%.

Data from the glacial geology map show excellent agreement with the above percentages when one considers the variation in definition of areas. Residual soil areas comprise 71%, Illinoian drift 19%, and valley train and outwash plain sediments 8% of the total area. A First Degree Uniformity Rating of II (Uniform) to III (Slightly Uniform) has been assigned, as shown in Table 8.

The agricultural soils information also provides excellent agreement with the above data. Residual sandstone and shale, with intermittent loess covering in places, makes up at least 61% of the total, consisting of soil type numbers 19 and 18, having 22% and 39%, respectively. Soil type number 59 comprises 8% of the area and is derived from limestone and limey shale residual. Stream bottom and sand and gravel terrace soils amount to 5% of the total as soil type number 12, and Illinoian till with intermittent loess cover in places makes up 19% of the area as soil type number 15.

Terrain Elevation Interval data conform to the Type 3 curve descriptive of the rolling to rugged topography which is known to occur in this area. The Wisconsin glacial boundary forms the northern boundary

for this physiographic region. Therefore, Drift Depth Interval information is not available. As one would expect, in this area, excavation far exceeds special borrow required on the average highway project. The data presented in Tables 3, 4, 5, 6 and 9 tend to confirm the above conclusion, and also show that rock cut is likely on the average highway project. Sand and gravel pits are rare in this subdivision. An Earthwork Factor of 2½ has been calculated for Interstate projects, indicating very little special borrow is used.

Bedrock of the Pennsylvanian System found in the western portion of this region is less resistant and of a poorer quality generally, than the Mississippian formations underlying the eastern portion.

However, as pointed out previously, the Mississippian limestones in the eastern section are soluble and pose an interesting problem. Solutioning, underground caverns and caves, a limited amount of sinkhole formation, subterranean drainage and spring development are some of the common features of these consolidated deposits. Peat excavation is not a significant consideration within this physiographic region of predominantly residual origin.

The data in Table 7 show 10 slope failures which are known to the writer. The instabilities occurred in six cuts and four embankments on residual soils, shale and weathered sandstone. In a few cases, the failure occurred at a side-hill cut-to-fill situation. This physiographic region is considered to have a high landslide potential, since it has the second highest number of slope failures for the regions studied within the State of Indiana.

### Wabash Lowland

The soil parent material areas occurring within this physiographic region are very complex in nature and origin. This area is also the largest of the physiographic subdivisions of southern Indiana, and the lowest ground surface elevations in the entire state occur here. Given the above facts, one could logically expect that a large portion of the region would consist of complex soils conditions, deserving more than average soils investigation activity. The engineering soil parent material map shows that potentially troublesome layered deposits occur over about 35% of the total area. The only widespread Eolian (loess) deposits in the State occur within this region and extend northward a short distance into the Tipton Till Plain. Loess covers about 31% of the Wabash Lowland. Interbedded sandstone and shale, with occasional layers of coal from the Allegheny Series of the Pennsylvanian System accounts for 13% of the total area, and it generally occurs in the southeastern portion. Old (Illinoian) till comprises 16% of the area, and sands cover about 5%.

Glacial geology data indicate residual soils make up about 22% of the total area, with Illinoian till accounting for approximately 37%. Lacustrine areas are shown as 14%, and valley train and outwash plain sediments comprise 24%. Apparently the engineering soils map does not distinguish between lacustrine deposits and valley train and outwash **plain** sediments. The data in Table 8 indicate a First Degree Uniformity Rating of IV (Complex).

The agricultural soils map shows that loess deposits make up at least 25% of the total area, with Soil type numbers 25, 26 and 27 accounting for 6%, 14% and 5%, respectively. Illinoian till and till with an

intermittent loess cover in places makes up 11% and 8% of the total area, and is shown as soil type numbers 15 and 14, respectively. Percentages of 13 and 6 were obtained for Soil type numbers 12 and 55, respectively, which were derived from stream bottom and sand and gravel terrace deposits. Residual sandstone and shale with an occasional loess cover makes up about 11% of the area as soil type number 19 and lakebed deposits, shown as soil type number 37, accounts for 5%.

Data for the Terrain Elevation Intervals indicate a Type 2 curve. The terrain varies from almost level to gently undulating to gently rolling, depending upon the landform and location within the region. Again, the southern boundary of Wisconsin glaciation is the northern boundary of this region, and Drift Depth Interval data are therefore not available. The other data presented in Tables 3, 4, 5, 6 and 9 tend to confirm the above conclusions. The occurrence of rock cuts and quarries is quite limited, and there is an abundance of sand and gravel pits. Quantities of excavation and special borrow appear to depend largely on the location of the project within the region. Some projects required much special borrow, others were balanced, and still others had excesses of excavation. This principally indicates a variation in topography with geographic location within the region. An earthwork factor of 36% has been calculated for this region indicating more excavation than special borrow for an average Interstate project. It can be seen from Tables 3, 4 and 5 that peat excavation is not a major consideration.

The region has been given a rating of moderate landslide potential. Table 7 records three slope failures, all in residual soil and shale cuts in the southern portion of this region.

Summary for Generalized Quantification of Significant Factors  
Influencing a Regional Approach to Highway Soils Considerations

It has been stated that the significant factors influencing a regional approach to highway soils considerations are: the geologic origin and complexity of parent materials, landforms and topography, and the general texture of the parent materials, particularly the size of the clay fraction. This section summarizes methods for expressing the first two of these three factors.

In quantifying the topography within physiographic regions, data were compiled so that a distribution curve, "Terrain Elevation Interval vs Percent Area Physiographic Region", could be drawn. The details for compiling these data were explained previously. Three characteristic type curves were obtained. These are:

Type 1. A high peak value for Percent Area Physiographic Region and a narrow range for Terrain Elevation Interval characterize this curve. Slight local relief and minor topographic expression are generally implied, i.e., almost level to gently undulating terrain.

Type 2. This curve has a moderate to high peak value for Percent Area Physiographic Region and a moderate to wide range for Terrain Elevation Interval. It generally indicates moderate variations in local relief and moderate topographic expression, i.e., gently undulating to rolling terrain.

Type 3. Characterizing this curve is a small to moderate peak value for Percent Area Physiographic Region and a wide range for Terrain Elevation Interval. Large variations in local relief and major topographic expression are implied by these curves, e.g.,

rolling to rough terrain.

A tabulation of the Terrain Elevation Interval Curve Types for each physiographic region has been included in Table 9. Thus, if one knows the curve type for the physiographic region, he can infer the generalized topography. The curves proper have been included in Appendix B.

Another method for generalized terrain quantification consisted of Normalizing Earthwork Quantities by Physiographic Regions for Interstate, Primary and Secondary classes of highways. These data are shown in Tables 3, 4 and 5, respectively. An Earthwork Factor,  $E(\%)$  was defined as the ratio of normalized special borrow to the normalized total earthwork (normalized special borrow plus normalized excavation). A tabulation of these values are shown in Table 9. The larger values are interpreted to indicate more level topography and the smaller values rougher terrain. However, it should be noted that these values are also dependent upon the standard requirements for alignment, grades and slopes for the various classes of highway projects.

The geologic origin and complexity of parent materials within each physiographic region were generally quantified in several ways, as follows:

A. Data were compiled as explained previously so that a distribution curve, "Drift Depth Interval vs Percent Area Physiographic Region" could be drawn. Two characteristic type curves were obtained:

Type 1. This is a normal distribution curve, i.e., it has low percentages for extreme values and has its peak value at or near the distribution mean. It can generally be inferred that bedrock



will not be encountered on the average project in physiographic regions where this type curve was obtained.

Type 2. The characteristics of this curve are similar to those for the right side of a normal distribution curve. That is, the curve peaks near the left extreme instead of near the mean value. Since the left extreme is the Drift Depth Interval of 0 to 50, bedrock may be encountered on an average project. The probability of actually encountering bedrock on a project is dependent upon the actual percentage for the 0 to 50 interval, and, to a lesser degree, for the 50 to 100 interval.

A tabulation of the Drift Depth Interval Curve Types for each physiographic region has been included in Table 9, for the area north of the Wisconsin Glacial Boundary. Thus, if one knows the curve type within the physiographic region, he can infer the thickness of drift and whether there is much likelihood that the consolidated formations (bedrock) will be encountered. The curves proper have been included in Appendix B.

B. Bar graphs for each significant Soil Type and Number were prepared as discussed previously for each physiographic region. They are included in Appendix C. "Significant" has been defined as 5% or more of the total area of the physiographic region. The smaller the number of soil types or numbers within a physiographic region, generally the higher is the uniformity within that region. Thus a generalized rating has been proposed as shown in Table 8. Very uniform conditions have been given a "First Degree Uniformity Rating" of I, and a complex condition has been given a rating of IV.

Intermediate ratings uniform II and slightly uniform III.

C. An indication of the occurrence of peat, marl and/or muck within physiographic regions has been presented in Tables 3, 4 and 5 in the form of peat excavation quantities on Interstate, primary and secondary highway projects.

D. Normalized Rock Quarry and Sand and Gravel Pit Data were also prepared for each physiographic region. The information has been tabulated and bar graphs prepared, which are included as Table 6 and Figure 14, respectively. The data can be used as indicators of the occurrence of valley train, outwash or other granular sediments within any physiographic region, as well as a possible indicator of shallow occurrence of quality bedrock.

E. A Summary of Slope Failures Per Physiographic Region has been prepared as Table 7. An examination of the information clearly indicates that certain physiographic regions are more landslide susceptible than others. It further shows that certain soil parent material areas within these physiographic regions are more failure prone than others. These ratings reflect only the slope failures which have developed in each physiographic region. In general, adequate soil and foundation investigations were made in the design or construction stages and/or remedial measures were taken to avoid instabilities.

## SPECIFIC QUANTIFICATION OF SIGNIFICANT FACTORS INFLUENCING A REGIONAL APPROACH TO HIGHWAY SOILS CONSIDERATIONS

The three dominant factors cited by McKittrick (48) were the geologic origin and complexity of parent materials, topography and landforms, and the general texture of the parent materials (particularly the amount of clay sizes). The methods used to quantify specifically these factors are presented in the following paragraphs.

### Methods of Specific Quantification Within Physiographic Regions

The degree of practicable quantification is a function of the input data available, i.e., the more detailed the information, the more specific can be the conclusions. A large amount of detailed information was available in the form of completed Roadway Soil Surveys and this information was employed in several ways, including statistically. As stated previously, the "Ratings of Highway Soils Considerations for Landforms within Physiographic Regions" presented in this section, are considered to be the most useful information resulting from this study, particularly for soils engineers inexperienced in this geographical location.

### Distribution of Interstate Mileage Within Physiographic Regions, Landforms and Soil Types

In any attempt specifically to quantify the factors affecting a regional approach to highway soils considerations, one of the first questions to be answered might be: "What landforms or soil types do our

highways traverse?" The method used to provide an answer for the Interstate highway system is discussed in the following paragraphs.

A projector slide of the physiographic regions and the Interstate highway system in Indiana was prepared. The slide image was projected onto the map "Engineering Soil Parent Material Areas of Indiana", and the mileage of Interstate highway within each parent material area was measured and recorded for each physiographic region. The Interstate mileage within each parent material area was then converted to a percentage of the total Interstate mileage within the physiographic region. These percentages have been included as a part of Table 11.

Included in the Table is similar information for the landforms shown on the map, "Glacial Geology of Indiana", and for the soil types shown on, "A Map of Indiana Soils". Also shown are columns for: the Approximate Total Interstate Mileage Within Physiographic Regions, the Approximate Area Within Physiographic Regions, and the Normalized Interstate Mileage Per Unit Area Within Physiographic Regions. Development of similar information for Primary and Secondary highways has been left as an exercise for future investigators.

#### Roadway Soil Survey Data for Cuts by Physiographic Region for Indiana State Highway Commission Projects

Very effective inferences about the adequacy of standard design backslopes and whether rock excavation will be required on a given project can be gained from a study of the cuts on previously constructed projects.

The information developed gives the number, depth and length of cuts for each of the Interstate, Primary and Secondary classes of highways





Within each physiographic region, since it was considered that the various requirements for alignment, grades and slopes would have a significant effect on the information compiled. These data consisted of average, maximum and minimum values for the number of cuts, the number of cuts in soil, the number of cuts in soil less than 10 ft. deep, the number of cuts in soil between 10 and 25 ft. deep, the number of cuts in soil greater than 25 ft. deep, the number of cuts where weathered rock was encountered above proposed grade, the number of cuts where rock was encountered above proposed grade, the number of rock cuts with less than 10 ft. of rock above proposed grade and the number of rock cuts with more than 10 ft. of rock above proposed grade.

Some of these data were normalized, that is, reduced to a per mile basis. These are the per mile number of cuts, the number of cuts in soil greater than 10 ft. deep, the number of cuts in soil less than 10 ft. deep, the number of cuts in weathered rock, and the number of cuts in rock.

Data related to the cut lengths were also developed. The average, maximum and minimum length of cuts in each physiographic region were determined from the available roadway soil surveys.

More refined information was compiled for rock cuts. For cuts with less than 10 ft. of rock above proposed grade the average, maximum and minimum values were determined for: the total depth of cut in feet; the thickness of weathered rock above proposed grade in feet; the thickness of rock in feet; the thickness of weathered rock to the average total depth of cut in percent; and the thickness of rock to the average total depth of cut in percent. This same type of information was determined



for cuts with more than 10 ft. of rock above proposed grade.

All of the above data have been presented in Table 12. These data can be used as indicators of the nature of the terrain, the adequacy of standard design back slopes and the frequency of occurrence of rock cuts. The lesser number and depths of cuts indicate more level terrain; the lesser average depth of cuts imply more stable backslopes. The frequency of rock cuts is especially useful information south of the Wisconsin Glacial Boundary, where thickness of drift information is not available.

#### Specific Terrain Quantification Factors for Physiographic Regions

Since terrain has been shown to be one of the more significant factors influencing a regional approach to highway soils considerations, an attempt has been made to determine a quantitative approach to terrain description. Turner and Miles (66) describe Fisher's dispersion factor,  $K$ . This factor approaches infinity for smooth surfaces and unity for very rough terrains. However, it was felt that this procedure was more applicable to more limited areas than those under consideration here.

The approach used in this study consisted of determining several descriptors for the Terrain Elevation Interval Curves included in Appendix B. The Coefficient of Variation or Dispersion,  $V(\%)$ , a statistical tool, defined as the standard deviation over the mean value, was one of the possibilities investigated. The statistical formulas used for determining the standard deviation and the mean values are shown in Appendix D, Section 1. A tabulation of the Coefficient of Variation for each physiographic region is shown in Table 13.

Another factor was defined for the purposes of this study, the

### For Cuts by Physiographic Region for ISHC Projects

### For Cuts by Physiographic Region for ISHC Projects

[illegible]

Table 13

## Summary of Terrain Quantification Factors for Physiographic Regions

	Physiographic Region	Coefficient of Variation, V(%)	Topographic Coefficient, T(%)
1.	Northern Lake and Moraine Region		
	A. Calumet Lacustrine Plain	22.5	9.6
	B. Valparaiso Moraine Area	17.4	7.8
	C. Kankakee Outwash and Lacustrine Plain	23.6	10.6
	D. Steuben Moraine Lake Area	23.8	8.3
	E. Maumee Lacustrine Plain	0	100.0
2.	Tipton Till Plain	22.8	3.7
3.	Dearborn Upland	29.8	2.4
4.	Muscatatuck Regional Slope	25.8	3.1
5.	Scottsburg Lowland	25.3	5.0
6.	Norman Upland	26.5	2.9
7.	Mitchell Plain	19.3	5.2
8.	Crawford Upland	27.2	3.1
9.	Wabash Lowland	26.0	7.2

Topographic Coefficient,  $T(\%)$ . It is the maximum ordinate or percentage of area of the physiographic region divided by the number of contour intervals. These values were taken directly from the curves in Appendix B. The values for the Topographic Coefficients for each physiographic region are also shown in Table 13.

#### Typical Profiles and Physical Properties of Soils for Significant Landforms within Physiographic Regions

If one can demonstrate some degree of uniformity or frequency of occurrence for the Soil types encountered within each significant landform within a physiographic region, he will have reached a second degree for Measure of Uniformity. The first degree of uniformity was discussed previously under the heading "Interpretation of Generalized Quantification within Physiographic Regions".

To present these frequency of occurrence data, and to correlate the data and implications from the maps available for the various disciplines, Typical Profiles were developed for each significant landform within a physiographic region. Only one region was accorded detailed study, viz., the Calumet Lacustrine Plain, a subsection of the Northern Lake and Moraine Region. Development of the Typical Profiles for landforms within the other physiographic regions was left as an exercise for future investigators.

Physical properties of the soils in each significant landform were subjected to statistical methods and procedures in an attempt to characterize each significant layer or stratum within each Typical Profile. Since economy is a major factor in the performance of any roadway soil survey, sufficient data were not always available. In areas where it



was intuitively obvious that the proposed conditions would pose no challenge to the existing foundation soils, detailed information was not requested or supplied. This was the case for several of the strata involved in the Typical Profiles developed for this study. The methods used in the development of the Typical Profiles and in the physical soil property study follow.

#### Typical Profiles for Significant Landforms within Physiographic Regions

Typical profiles were prepared for each of the three significant landforms or soil parent material areas as defined by the map "Engineering Soil Parent Material Areas in Indiana", in the Calumet Lacustrine Plain. "Significant" has been defined as more than 5 percent of the physiographic region area. Thus, typical profiles were prepared for the dune sand, lakebed, and ground moraine (Wisconsin) areas, which constitute about 66, 12 and 13 percent, respectively, of the approximate 279 square miles total.

One needs to make use of all conveniently available sources to avoid erroneous conclusions. For example, consider the large area shown as dune sand on the map of Engineering Soil Parent Material Areas in Indiana. If we consider this information, along with that of "A Map of Indiana Soils" (Pedologic), impression is gained that sand is the engineering material. (Pockets, layers and lenses of peat, marl and other organic soils are expected in the depressions between the sand dunes.) However, the entire soil parent material area shown as dune sand is underlain by a deep deposit of lacustrine sediments from Glacial Lake Chicago, consisting of compressible fine grained soils. This fact would be evident

from the map, "Glacial Geology of Indiana". The consolidation of these underlying deposits due to superimposed loading might well control the design of many facilities.

An important part of the Typical Profile is the Statistical Soil Classification, which is based on average values for the pertinent physical characteristics used in the Textural and in the AASHTO (American Association of State Highway Officials) Classification Systems. These values were obtained from Roadway Soil Surveys performed for the Indiana State Highway Commission by consultants. The percentages of sand, silt and clay sizes, along with the amounts passing the No. 10, 40 and 200 U.S. Std. sieves, were determined from the mechanical analysis test. Liquid limit and plasticity index percentages were determined as a part of the Atterberg Limit tests.

A somewhat arbitrary decision was required for soils revealed by test to be non plastic (NP). Mere deletion of these results would yield mean values for the liquid and plastic limits which were too high. Giving the liquid and plastic limits a value of zero would have resulted in mean values which were too low. Consequently, the NP samples were assigned a value equal to the lowest value obtained for any sample within the soil stratum for the landform and physiographic region under discussion.

The Indiana State Highway Commission specifications entitled "Requirements for Roadway Soil Survey" state that in general, the Textural and AASHTO classifications shall be determined for each soil type encountered per mile of roadway length. If upon visual examination in the field it appeared that a soil type was encountered in two or more borings within the same mile, only one was tested. Therefore, the amount



of data available depended upon the complexity of the parent materials, as well as the number of projects for which consultant Roadway Soil Surveys were available, and the length of each project.

Three different methods were used in determining the Statistical Soil Classification. The first was based on an un-weighted average procedure and the remaining two used a weighted average principle. An explanation of each of the methods follows:

Method 1. This method is based on an un-weighted average procedure. The classification test data for each major soil parent material area within the physiographic region were simply tabulated and grouped together to determine a frequency factor ( $f_1$ ) for each test value of the physical characteristic under consideration. The un-weighted mean value ( $\bar{x}_1$ ) and the standard deviation ( $s_1$ ) were determined using the expressions in Appendix D, Section 2. These mean values of each of the physical characteristics necessary to classify the soil were used to determine the Statistical Soil Classification.

Method 2. A weighted average procedure was employed in this method. The same classification test data tabulated for Method 1 were used, but a different frequency factor ( $f_2$ ) was determined. This frequency factor was found by counting the number of times a given soil type was encountered on the soil profile drawings. Then these values were combined for each test value of the physical characteristic under consideration for every soil type. The weighting was accomplished by determining the number of times any given soil type was encountered, and, in essence, combining it with the frequency factor ( $f_1$ ). This resulted in a more

accurate frequency distribution of the soils encountered within the areas investigated. The weighted mean value ( $\bar{x}_2$ ) and the standard deviation ( $s_2$ ) were determined as before, along with the Statistical Soil Classification.

Method 3. Another weighted average procedure was employed in this method, thought to involve a more accurate indicator of the frequency distribution of the soils encountered. A frequency factor ( $f_3$ ) was determined in a similar manner to that of Method 2, but considering the thickness of the layer as well as the number of times any given soil type was encountered. The frequency factor ( $f_3$ ) was found by measuring the thickness of each soil layer encountered (as shown on the soil profile drawings) and combining these values for each test value of the physical characteristic under consideration for every soil type. The weighting was accomplished by determining the total thickness of any given soil type encountered and essentially combining it with the frequency factor ( $f_2$ ). This method resulted in the most accurate frequency distribution of the soils encountered. The weighted mean value ( $\bar{x}_3$ ) the standard deviation ( $s_3$ ) and the Statistical Soil Classification were determined as before.

A summary of the mean values determined for each Typical Profile along with the resulting statistical classifications has been prepared. The "Data for Statistical Soil Classification" for Typical Profile No. 1, the dune sand landform underlain by lakebed sediments, is shown in Table E-1, Appendix E. Similar data for Typical Profile No. 2, the surficial lakebed landform underlain by what is considered to be dune sand, is included in Table E-2. In Table E-4 is included similar information for Typical Profile No. 3, the Wisconsin ground moraine landform.

Also included in these tables are the resulting statistical soil classifications based on the Textural and the AASHTO classifications.

Detailed boring, sampling and test data were not available for all of the unconsolidated strata which overlie the bedrock in this region. This is consistent with the notion that every engineering project should be built as economically as possible while exercising mature engineering judgement for every phase of planning, design, and construction. The borings were taken just deep enough to provide adequate information for design of the modern highway facilities, working within the framework of current standards. The remainder of the information shown on the typical profiles, viz., the non-statistical soil and bedrock descriptions, some of the soil strata changes, and the bedrock depth, were determined from soil boring and well records (68, 69) and from the "Map Showing Thickness of Drift in Indiana North of the Wisconsin Glacial Boundary". Typical Profiles for the dune sand landform, for the lakebed landform, and for the Wisconsin ground moraine landform are shown in Figures E-1, E-8 and E-12, respectively, in Appendix E.

#### Physical Properties of Soils in Significant Landforms Within Physiographic Regions

A general knowledge of the physical properties of soils in an area of interest is most useful to practicing soils engineers, in their attempt to anticipate the highway soils problems associated with the given area. Considerable detailed data of this nature were accumulated as a part of the Roadway Soil Surveys performed for the Indiana State Highway Commission by consultants. These data were compiled, statistical methods were applied to determine the linear regression equations, and in a few cases

the quadratic regression equations were developed. This information was then plotted and the curves drawn. Most of these data are presented in Appendix E.

As a matter of routine, soaked California Bearing Ratio (CBR) information is developed for the major soil types likely to be used in the subgrade of the proposed highway. This information is used in the design of pavements. Before the CBR values can be determined, it is necessary to determine the Standard Moisture-Density relationship for the major soil types. The data for Typical Profile No. 1, Stratum A, Dune Sand Landform, and for Typical Profile No. 3, Stratum A, Wisconsin Ground Moraine Landform, were compiled and statistical methods were applied. The linear regression equations for molding moisture content vs. molded dry density and wet density, and for molded dry density vs. soaked CBR were determined using the equations presented in Appendix D, Section 3. The method of Least Squares was used for fitting a straight line to the data and determining the linear regression equation. The prediction equation was then checked for significance of regression by the "F-Test" procedure, after the Analysis of Variance Table (Anova) was prepared. It was also checked for "Goodness of Fit". Finally, the 95% Confidence Limits for the True Mean Value of Y were determined. The methods and procedures for determining the above are shown in Appendix D, Section 3. The plotted data, linear regression equations, 95% confidence limits, and conclusions are shown on Figures E-2 and E-13 for the dune sand and Wisconsin ground moraine landforms, respectively. Also shown are average values for the maximum wet density, moisture content at the maximum wet density, maximum dry density, optimum moisture content, and the CBR value

for specimens molded at 90%, 95% and 100% of the maximum dry density.

Second order or quadratic regression equations were then determined using the formulas and procedures outlined in Appendix D, Section 4. The Analysis of Variance Table was prepared and the quadratic regression equation was checked for significance of regression by the "F-Test" procedure. The "Sequential F-Test Criterion" was used to determine if the addition of the second term,  $X^2$ , was useful. Then the 95% Confidence Limits for the True Mean Value of Y were determined. The plotted data, quadratic regression equations, 95% confidence limits and conclusions where applicable, are shown on Figures E-2 and E-13.

Other useful relationships were investigated, and the regression equations determined for the lakebed soils comprising Stratum B of Typical Profile No. 1. The relationships and linear regression equations for liquid limit vs. plasticity index and compression index are shown in Figure E-3, included in Section 1 of Appendix E. The former was compared with Casagrande's "A"-Line (61, page 35) and the latter was compared with the relationship of (61, page 66). On Figure E-4 are shown relationships for standard penetration test value vs. unconfined compressive strength and plasticity index vs. ratio of shear strength to effective overburden pressure. The former was compared with the relationship of (61, page 300). The natural moisture content vs. log unconfined compressive strength for the linear and quadratic relationships are shown in Figure E-5. Whenever the log of the ordinate or Y value is required in the statistical procedures, one simply substitutes the log of Y values into the method of least squares and proceeds as usual. These relationships were compared with (36, Figure II-11). Linear and quadratic

relationships were determined for natural moisture content vs. log standard penetration test value. This information is shown on Figure E-6.

Very limited information was available for the glacial drift hardpan material which characterizes Stratum C of Typical Profile No. 1. This is due to several reasons. The hardpan is encountered at considerable depths below the existing ground, lying just above the bedrock. Therefore, it may not have been encountered within the limits of the Roadway Soil Survey investigations. In general, this stratum is very dense or hard, having low moisture contents, high strengths, and low compressibility. Therefore, the need for detailed information was small. There was some limited data for natural moisture content vs. log unconfined compressive strength; the linear regression equation is shown on Figure E-7.

A very limited amount of detailed data was available for Typical Profile No. 2, which is the surficial lakebed landform. The upper part of this formation is desiccated and relatively strong. Thus for average or normal design and construction conditions, detailed data are not requested. The data used in determining the statistical soil classifications are included in Table E-2 of Appendix E, Section 2, along with the appropriate soil classification. In Figure E-9 is shown the liquid limit vs. plasticity index relationship and the linear regression equation. Casagrande's "A"-Line has been shown for comparison. The natural moisture content vs. log standard penetration test value relationship is given in Figure E-10. Also shown on that Figure is the appropriate linear regression equation. To show the effects of desiccation at the shallower depths, a plot of standard penetration vs. depth was prepared. It was



not considered necessary to determine a regression equation for the data, but an average "N-Value" line has been shown as a part of Figure E-11. To supplement the previously mentioned data, isolated test results were compiled and included in the Summary of Special Test Results, Table E-3. These included results of natural moisture content, natural dry density, initial void ratio, compression index, preconsolidation stress, maximum wet and dry densities, optimum moisture content and the soaked California bearing ratio results for specimens molded at 90, 95 and 100 percent of the maximum dry density.

The detailed soil test results for Typical Profile No. 3, the Wisconsin ground moraine landform, has been compiled and included in Appendix E, Section 3. The statistical soil classification data are included in Table E-4 along with the appropriate soil classifications. Moisture-density relations along with soaked California bearing ratio vs. dry density data similar to those described for Typical Profile No. 1, have been included as a part of Figure E-13. Both the linear and quadratic regression equations have been included. A linear regression equation has been shown on Figure E-14 for the liquid limit vs. plasticity index relationship for Stratum A of this landform. Again, Casagrande's "A"-Line is shown for comparison. The relationship between plastic limit and maximum dry density has been included on Figure E-15, along with the linear regression equation. Limited data were available for standard penetration test value vs. unconfined compressive strength, however, these were used to determine the linear regression equation shown on Figure E-16. The natural moisture content vs. log unconfined compressive strength relationship, including the linear regression equation, is shown

in Figure E-17. The linear regression equation shown on Figure E-18 is for the relationship between the natural moisture content and the log standard penetration test values.

It is intended and anticipated that as additional data become available, they can be added to the existing data, resulting in more meaningful regression equations and related statistical conclusions. In this way, a more definite position can be taken toward showing homogeneity or heterogeneity within the landforms for the various physiographic regions.

#### Ratings of Highway Soils Considerations for Landforms Within Physiographic Regions in Indiana

It was emphasized previously that the writer considers the information developed and presented in this section of the study to have the greatest potential use for practicing soils engineers, who are inexperienced in this geographical location. The usefulness of these data could be expanded several fold, if other practicing soils engineers experienced in this locale would offer constructive criticism of this presentation, and if their thoughts and experiences could be incorporated in a modified presentation. It is felt that the usefulness of this information lies within the realm of "preliminary considerations" related to highway planning, route location, design, and construction. As mentioned previously, these ratings reflect the present standards, policies and procedures used by the Indiana State Highway Commission for the design and construction of modern highway facilities.

The information included in Table 14 is entitled, "Ratings of Highway Soils Considerations for Landforms within Physiographic Regions

TABLE 14 RATINGS OF HIGHWAY SOILS CONSIDERATIONS FOR LANDFORMS WITHIN PHYSIOGRAPHIC REGIONS OF INDIANA

[illegible]

Note: L (Low), M (Medium), H (High) - Indicates there is little, average, high likelihood of major (deserving detailed consideration) problems developing, respectively.



TABLE 14 (CONT.)

PHYSIOGRAPHIC REGION	PHYSIOGRAPHIC DISCRIMINANTS	PREDOMINANT SOIL AND ROCK TYPES	HIGHWAY SOILS CONSIDERATIONS																																					
			CUT DESIGN							EMBANKMENT DESIGN						EMBANKMENT FOUNDATIONS							SUBGRADES				STRUCTURE DESIGN										MISC			
																											WITH FOOTINGS					WITH PILES								
			A	B	C	D	E	F	G	A	B	C	D	E	F	A	B	C	D	E	F	G	H	I	A	B	C	D	A	B	C	D	E	F	G	H	I	A	B	
2 TIPTON TILL PLAIN	END MORaine, KAMES AND ESKERS (WISCONSIN)	SILT, SAND AND CLAY	L		M	M	M		M	L		L		M	M	M	M	M	L	L			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	GROUND MORaine (WISCONSIN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	VALLEY TRAIN (WISCONSIN)	SAND, SILT AND GRAVEL	L		L	H	H		L	L		L		H	H	L	L	L	L	L	L			L	L	H	L	L	L	L	L	H	L	L	L	H	L			
	ALLUVIUM (RECENT)	SILT, CLAY AND SAND	M		M	H	H		M	L		L		H	H	H	M	M	M	H			M	H	M	M	M	M	H	H	H	M	M	H	H	H	L			
	LOESS (WISCONSIN)	SILT, SAND AND CLAY	M		L	H	H		H	L		M		H	H	M	M	L	L	L			M	M	M	M	M	M	H	L	L	M	M	H	H					
	LACUSTRINE (WISCONSIN)	SILTY CLAY AND CLAY	M		L	M	M		M	L		M		M	M	H	H	L	L	M			H	H	L	M	H	H	H	M	M	M	H	H	M	H				
	DEPRESSIONS (RECENT-WISCONSIN)	PEAT AND MUCK - MARL	H		L	H	H		H	H		H		H	H	H	H	L	H	H			H	H	L	L	H	H	H	H	H	M	M	H	H	H				
	ISOLATED AREAS	SOIL (UNDIFFERENTIATED)	L		L	M	M			L		L		M	M	M	M	L	L	M			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	(SILURIAN-PENNSYLVANIAN)	BEDROCK (LIMESTONE, DOLOMITE AND SHALE IN NORTHEAST SECTION - SHALE IN WEST SECTION)	L-M						L		L-M		L-M										L																L	
3 DEARBORN UPLAND	GROUND MORaine (WISCONSIN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M	M			
	GROUND MORaine (ILLINOIAN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	END MORaine, KAMES AND ESKERS (WISCONSIN)	SILT, SAND AND CLAY	L		M	M	M		M	L		L		M	M	M	M	M	L	L			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	VALLEY TRAIN (WISCONSIN)	SAND, SILT AND GRAVEL	L		L	H	H		L	L		L		H	H	L	L	L	L	L	L			L	L	H	L	L	L	L	L	L	L	L	L	L	L			
	ALLUVIUM (RECENT)	SAND, SILT AND CLAY	M		M	H	H		M	L		L		H	H	H	M	M	H				M	H	M	M	M	M	H	H	H	M	M	H	H	H				
	LACUSTRINE (WISCONSIN)	CLAY AND SILT	M		M	M	M		M	L		M		M	M	H	H	M	L	H			H	H	L	M	H	H	H	M	M	M	M	H	H	M	H			
	RESIDUAL	SOIL (SILT AND CLAY)	H		H	M	M		H	L		M		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M				
		(ORDOVICIAN)	BEDROCK (INTERBEDDED LIMESTONE AND SHALE)	H						L		M		M										L																
4 MUSCATATUCK REGIONAL SLOPE	GROUND MORaine (WISCONSIN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M	M			
	GROUND MORaine (ILLINOIAN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	END MORaine, KAMES AND ESKERS (WISCONSIN)	SILT, SAND AND CLAY	L		M	M	M		M	L		L		M	M	M	M	M	L	L			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	VALLEY TRAIN (WISCONSIN)	SAND, SILT AND GRAVEL	L		L	H	H		L	L		L		H	H	L	L	L	L	L	L			L	L	H	L	L	L	L	L	H	L	L	L	H	L			
	LACUSTRINE (WISCONSIN)	CLAY AND SILT	M		L	M	M		M	L		M		M	M	H	H	L	L	H			H	H	L	M	H	H	H	M	M	M	H	H	M	H				
	ALLUVIUM (RECENT)	SILT, CLAY AND SAND	M		L	H	H		M	L		L		M	M	H	H	L	M	H			M	H	M	M	M	M	H	H	M	M	M	H	H	M	H			
	RESIDUAL	SOIL (SILT AND CLAY)	M		M	M	M		M	L		M		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M				
		(SILURIAN-DEVONIAN-ORDOVICIAN)	BEDROCK (LIMESTONE, DOLOMITE AND SHALE IN EAST SECTION - LIMESTONE, DOLOMITE, SANDSTONE AND SHALE IN WEST SECTION - ISOLATED AREAS OF INTERBEDDED LIMESTONE AND SHALE)	L-M						L		L-M		L-M										L																
5 SCOTTSBURG LOWLAND	GROUND MORaine (WISCONSIN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M	M			
	GROUND MORaine (ILLINOIAN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	END MORaine, KAMES AND ESKERS (WISCONSIN)	SILT, SAND AND CLAY	L		M	M	M		M	L		L		M	M	M	M	M	L	L			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	VALLEY TRAIN (WISCONSIN)	SAND, SILT AND GRAVEL	L		L	H	H		L	L		L		H	H	L	L	L	L	L	L			L	L	H	L	L	L	L	L	H	L	L	L	H	L			
	LACUSTRINE (WISCONSIN)	SILT AND CLAY	M		L	M	M		M	L		M		M	M	H	H	L	L	M			H	H	L	M	H	H	H	M	M	M	M	H	H	M	H			
	ALLUVIUM (RECENT)	SILT, CLAY AND SAND	M		L	H	H		M	L		L		H	H	H	H	L	M	H			M	H	M	M	M	M	H	H	H	M	M	H	H	M	H			
	RESIDUAL	SOIL (SILT AND CLAY)	M		M	M	M		M	L		M		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M				
		(DEVONIAN - MISSISSIPPIAN)	BEDROCK (LIMESTONE, DOLOMITE, SANDSTONE AND SHALE IN EAST SECTION - LIMESTONE AND SHALE IN WEST SECTION)	M						L		L		L										L																
6 NORMAN UPLAND	GROUND MORaine (ILLINOIAN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	LACUSTRINE (WISCONSIN AND ILLINOIAN)	SILT AND CLAY	M		L	M	M		M	L		M		M	M	H	H	L	L	H			H	H	L	M	H	H	H	M	M	M	M	H	H	M	H			
	ALLUVIUM (RECENT)	SILT, CLAY AND SAND	M		L	H	H		M	L		L		H	H	H	L	M	H			M	H	M	M	M	M	H	H	M	M	M	M	H	H	M	H			
	RESIDUAL	SOIL (SILT AND CLAY)	M		M	M	M		M	L		M		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M				
		(MISSISSIPPIAN)	BEDROCK (LIMESTONE, SANDSTONE, SILTSTONE AND SHALE)	M						M		L		L										M															H	
7 MITCHELL PLAIN	GROUND MORaine (ILLINOIAN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	M	M	M	M	M	M	M	M	M	M				
	LACUSTRINE (WISCONSIN AND ILLINOIAN)	SILT AND CLAY	M		L	M	M		M	L		M		M	M	H	H	L	L	H			H	H	L	M	H	H	H	M	M	M	M	H	H	M	H			
	ALLUVIUM (RECENT)	SILT, CLAY AND SAND	M		L	H	H		M	L		L		H	H	H	L	M	H			M	H	M	M	M	M	H	H	M	M	M	M	H	H	M	H			
	RESIDUAL	SOIL (CLAY AND SILTY CLAY)	M		M	M	M		M	L		M		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M				
		(MISSISSIPPIAN)	BEDROCK (LIMESTONE)	L						H		L		L										H															</	

NOTE: L(Low), M(Medium), H(High) - indicates there is little, average, high likelihood of major (deserving detailed consideration) problems developing, respectively.



TABLE 14 (CONT.)

PHYSIOGRAPHIC REGION	PHYSIOGRAPHIC DISCRIMINANTS	PREDOMINANT SOIL AND ROCK TYPES	HIGHWAY SOILS CONSIDERATIONS																																					
			CUT DESIGN							EMBANKMENT DESIGN						EMBANKMENT FOUNDATIONS									SUBGRADES				STRUCTURE DESIGN									MISC.		
																													WITH FOOTINGS					WITH PILES						
			A.	B.	C.	D.	E.	F.	G.	A.	B.	C.	D.	E.	F.	A.	B.	C.	D.	E.	F.	G.	H.	I.	A.	B.	C.	D.	A.	B.	C.	D.	E.	F.	G.	H.	I.	A.	B.	
8. CRAWFORD UPLAND	GROUND MORaine (ILLINOIAN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	M	M	M	M	M	M	L	L	M	M	M	M		
	LACUSTRINE (WISCONSIN AND ILLINOIAN)	SILT AND CLAY	M		L	M	M		M	L		M		M	M	H	H	L	L	H			H	H	L	M	H	H	H	H	M	M	M	H	H	M	H			
	ALLUVIUM (RECENT)	SILT, SAND AND CLAY	M		L	H	H		M	L		L		H	H	H	H	L	M	H			M	H	M	M	M	M	H	H	H	M	M	H	H	H	H			
	RESIDUAL	SOIL (SILT AND CLAY)	M		M	M	M		M	L		M		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M	M			
	(MISSISSIPPIAN- PENNSYLVANIAN)	BEDROCK ( INTERBEDDED LIMESTONE, SANDSTONE AND SHALE IN EAST SECTION- SHALE AND SANDSTONE IN WEST SECTION)		H				M			L		L									M																		
9. WABASH LOWLAND	GROUND MORaine (ILLINOIAN)	SILT, CLAY AND SAND	L		M	M	M		M	L		L		M	M	M	M	M	L	M			M	M	M	M	M	M	M	M	M	M	L	L	M	M	M	M		
	DUNES (WISCONSIN)	SAND	L		L	H	H		L	L		L		H	H	L	L	L	L	L	L		L	L	H	L	L	L	L	L	L	L	L	L	L	H	L			
	OUTWASH AND VALLEY TRAIN (WISCONSIN)	SAND AND GRAVEL	L		L	H	H		L	L		L		H	H	L	L	L	L	L	L		L	L	H	L	L	L	L	L	L	L	L	L	L	H	L			
	ALLUVIUM (RECENT)	SILT, SAND AND CLAY	M		M	H	H		M	L		L		H	H	H	H	M	M	H			M	H	M	M	M	M	H	H	H	M	M	H	H	H	H			
	LACUSTRINE (WISCONSIN AND ILLINOIAN)	SILT AND CLAY	M		M	M	M		M	L		M		M	M	H	H	M	L	H			H	H	L	M	H	H	H	H	M	M	M	H	H	M	H			
	LOESS (WISCONSIN)	SILT, SAND AND CLAY	M		L	H	H		H	L		M		H	H	M	M	L	L	L			M	M	M	M	M	M	M	M	H	L	L	M	M	H	H			
	RESIDUAL	SOIL (SILT AND CLAY)	H		H	M	M		H	L		M		M	M	M	M	M	L	M			M	M	M	M	H	H	M	M	M	L	L	M	M	M	M			
	(PENNSYLVANIAN)	BEDROCK (INTERBEDDED SHALE AND SANDSTONE WITH SOME COAL)		M-H				L			M		M									L																	H	

L (LOW)- INDICATES THERE IS LITTLE LIKELIHOOD OF MAJOR PROBLEMS DEVELOPING

M (MEDIUM)- INDICATES THERE IS AVERAGE LIKELIHOOD OF MAJOR PROBLEMS DEVELOPING

H (HIGH)- INDICATES THERE IS LARGE LIKELIHOOD OF MAJOR PROBLEMS DEVELOPING



in Indiana". It reflects the ten years of soils and foundation engineering experiences of the writer, and some of the experiences of close associates with more experience years. The Table shows, for each physiographic region, the principal physiographic descriptors, the predominant soil and rock types within the various landforms, and the ratings of highway soils considerations anticipated within these landforms. These ratings depend upon the size of the landform area as a percentage of the total area of the physiographic region. The smaller the percentage, the less the significance of the potential problem.

Ratings for some of the more important highway soils considerations (cut design, embankment design, embankment foundations, subgrades, structure design, and miscellaneous isolated potential problems) are shown in Table 14. The structural design considerations were separated into: footings, piles and lateral earth pressures for retaining structures. Ratings of L (Low), M (Medium) or H (High) were used to indicate little, average, or high likelihood that these items will require detailed consideration.

A review of Table 14 reveals that the greater frequencies of occurrence for certain classes of highway soils problems are largely associated with certain landforms or parent materials, regardless of the physiographic region. For example, organic soils such as peat, marl and/or muck are expected to require detailed consideration wherever they are encountered. Alluvial deposits are usually very erratic, relatively compressible and generally low in shear strength. Further, they occur in poorly drained topography, resulting in a very undesirable set of circumstances for foundation soils. Lacustrine deposits tend to have similar problems.



However, the lacustrine sediments, being associated with deposition in standing water, tend to be more uniform in composition than the alluvial sediments.

In connection with the lacustrine deposits, which seem to deserve more than average consideration from a soils engineering standpoint, a table of "Maximum Distribution of Lacustrine Deposits within Physiographic Regions" was prepared. It shows the maximum percentage of the area occupied by lacustrine deposits, determined by geologic, pedologic or engineering soils mapping. In addition, to Table 15, several small scale lacustrine deposit maps were located (62). These are: Figure 15, "Map of Southern Indiana showing Wisconsin Glacial Lakes and Sluiceways"; "Map of Southern Indiana showing Illinoian Glacial Lakes and Sluiceways", Figure 16; "Map Showing Sites of Glacial Lakes Quincy and Eminence", Figure 17.

A third dimension or degree for Measure of Uniformity is concerned with the materials or soil types encountered within each landform as was the second dimension. The distinction between these two degrees is that in the third, a grouping of soil types occurs based on anticipated similar behavior for a given class of soils problems. For example, if we have a large number of soil types, say gravel, gravelly sand, sandy gravel, sand, non plastic sandy loams and silty loams, we can consider these soils to react as relatively uniform or homogeneous foundation soils when considering the problem of foundation settlements under embankments. These soils are considered to have high to very high relative permeabilities. Thus, it would be anticipated that most of the settlements would occur essentially as the load is being applied during the

Table 15

## Maximum Distribution of Lacustrine Deposits in Each Physiographic Region

Physiographic Region	Maximum Distribution of Lacustrine Deposits as Percentage of Total Physiographic Region, %	ISNC Districts
1. Northern Lake and Moraine Region		
A. Calumet Lacustrine Plain	86	Laporte
B. Valparaiso Morainal Area	3	Laporte
C. Kankakee Outwash and Lacustrine Plain	16	Laporte, with eastern fingers in Ft. Wayne
D. Steuben Morainal Lake Area	3	Ft. Wayne, with western fingers in Laporte
E. Maumee Lacustrine Plain	91	Ft. Wayne
2. Tipton Till Plain	1	Cravfordsville and Greenfield; northwestern portion in La- porte, northeastern portion in Ft. Wayne and southeastern portion in Seymour
3. Dearborn Upland	1	Seymour, with northern portion in Greenfield
4. Mucatastuck Regional Slope	1	Seymour, with northern portion in Greenfield
5. Scottsburg Lowland	12	Seymour

Table 15 (cont'd)

## Maximum Distribution of Lacustrine Deposits in each Physiographic Region

Physiographic Region	*Maximum Distribution of Lacustrine Deposits as Percentage of Total Physiographic Region, %	ISHC Districts
6. Norman Upland	13	Seymour, with northern portion in Crawfordville
7. Mitchell Plain	6	Seymour and Vincennes, with northern portion in Crawfordville
8. Crawford Upland	9	Vincennes and Seymour, with northern portion in Crawfordville
9. Wabash Lowland	36	Vincennes, with northern portion in Crawfordville

\* Based on data shown in Appendix C, taken from either (1, 5, 73)

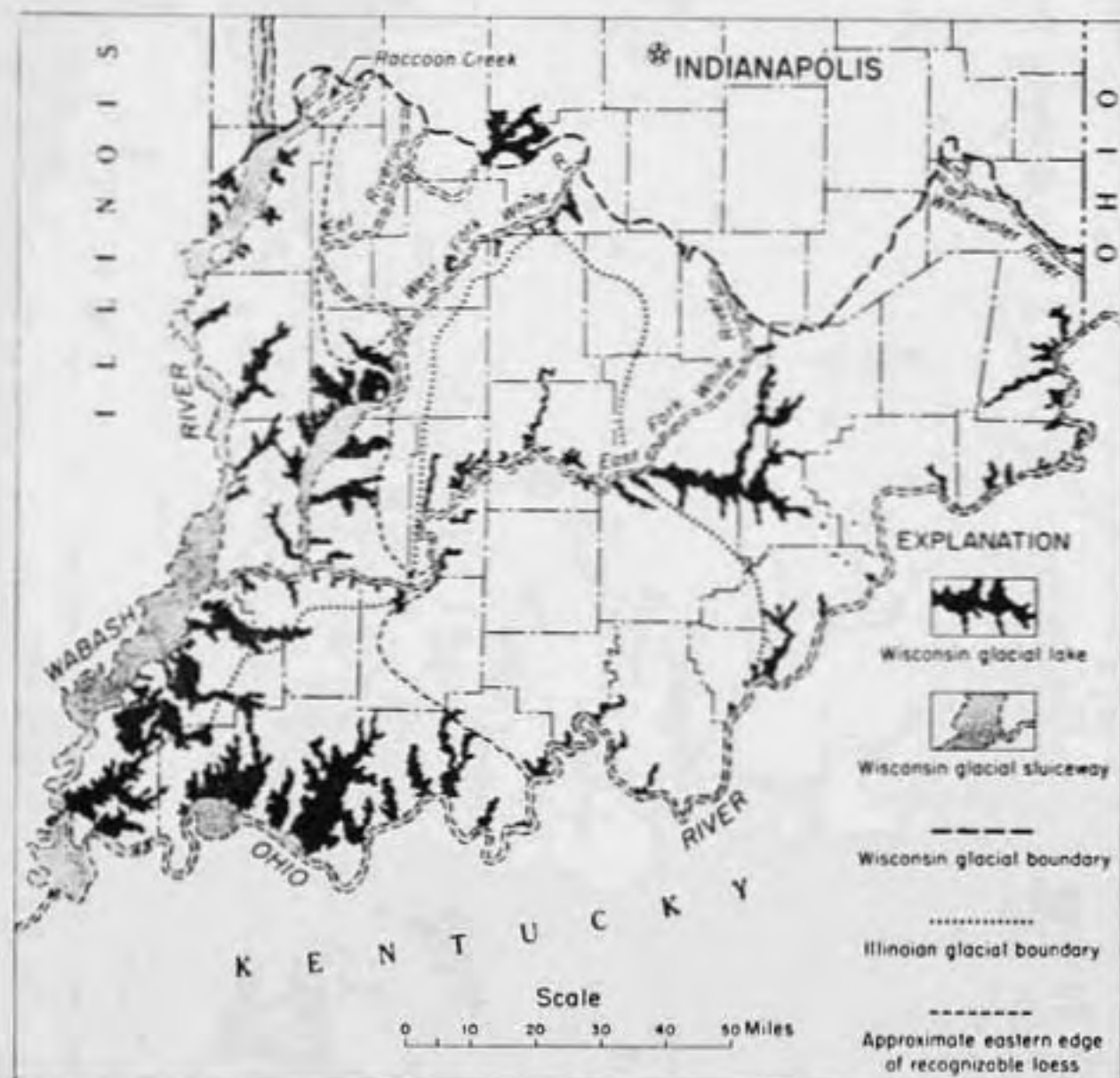


Figure 15 Map of southern Indiana showing Wisconsin glacial lakes and sluiceways.

AFTER THORNBURY (62)

## ILLINOIAN ALLUVIATION



Figure 16 Map of southern Indiana showing Illinoian glacial lakes and sluiceways.

AFTER THORNBURY (62)

## ILLINOIAN ALLUVIATION

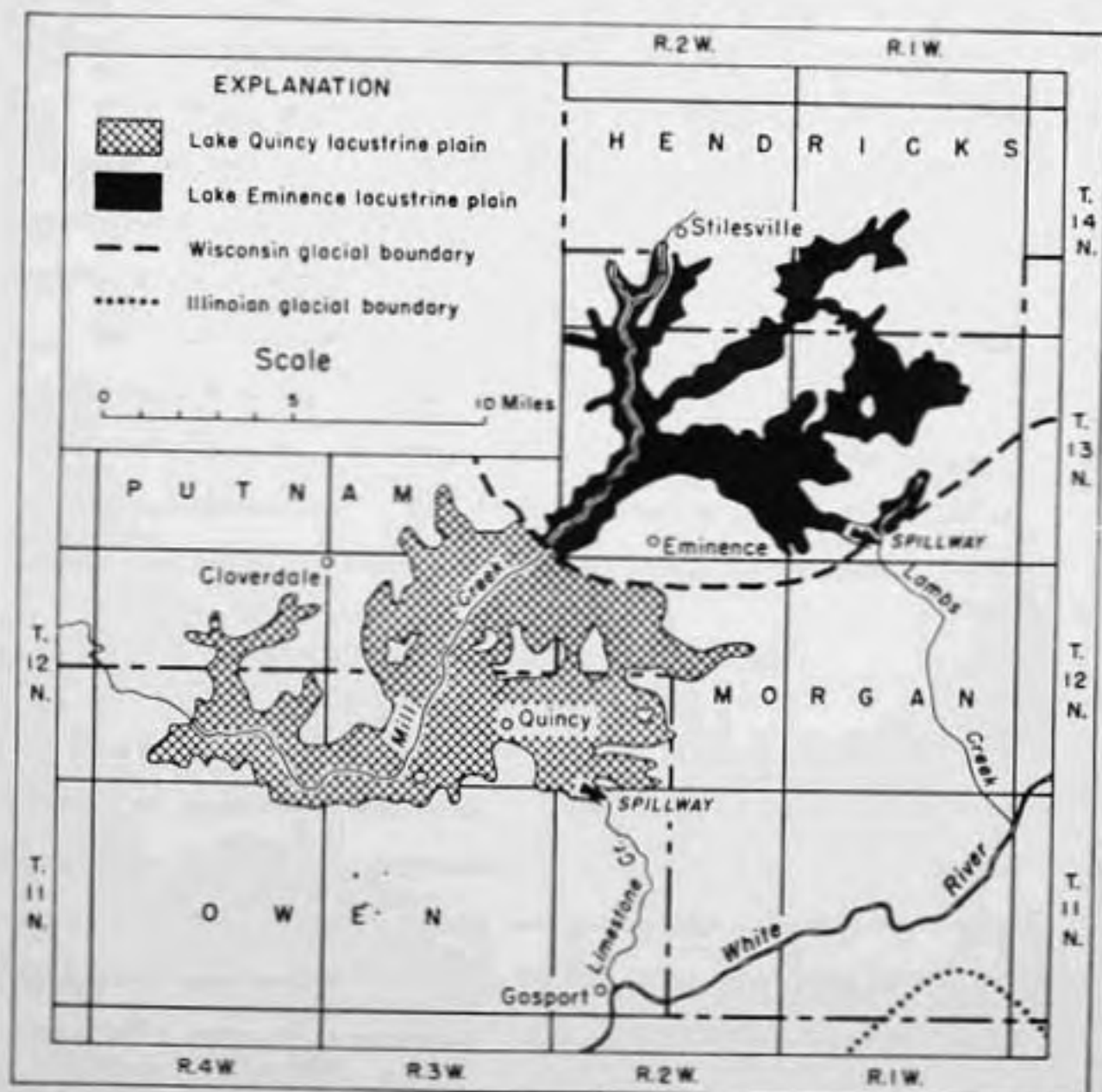


Figure 17 Map showing sites of glacial Lakes Quincy and Eminence.  
AFTER THORNBURY (62)



construction grading period and prior to the placement of any pavement.

The Table does seem to identify the physiographic regions and landforms within these regions where bedrock is likely to be encountered, and it provides some insight into the class and magnitude of problems associated with these parent materials. In general, the problems are stability and settlement of structures (including those constructed of soil and rock), control of ground and surface waters, erosion of slopes, solutioning- faulting- mining within bedrock landforms, handling and compaction of soils and rocks, and subgrade support (including frost action, pumping, shrink and swell).

The ratings of Table 14 should be used only for preliminary studies, to provide a starting point for soils engineers inexperienced in this geographical locale. One must always keep in mind that these ratings are generalizations within a landform and that detailed information is needed at a specific location before final decisions are made.

#### Some Comments and Interpretations of the Specific Quantification

The need for adequate methods specifically to quantify the significant factors which affect a regional approach to highway soils considerations becomes more pronounced as the size of the area of interest decreases. The methods of generalized quantification have potential use in physiographic region areas. If the area size is reduced to the project level, more detailed information is needed if one is to make worthwhile inferences about the landform homogeneity and the uniformity of soil types within the landforms. The results of the methods used in this investigation will be discussed subsequently.

### Conclusions about Terrain Quantification Factors for Physiographic Regions

As mentioned previously, the percentages for the Coefficient of Variation and for the Topographic Coefficient are included in Table 13, for data obtained from the Terrain Elevation Interval Curves shown in Appendix B. An examination of these results reveals some strong correlations and implications, which have been included in Table 16 entitled, "Conclusions about Terrain Quantification Factors for Physiographic Regions".

The Coefficient of Variation,  $V$ , is defined as the standard deviation over the mean value. Limits for this value have been arbitrarily set as shown in the Table. A value of  $V$  less than 5 indicates level to gently undulating topography. This is interpreted to imply "Lacustrine" deposits, such as those encountered in physiographic region 1E. When  $V$  is equal to or greater than 5 and equal to or less than 25, gently undulating to undulating topography can be expected. There seems to be a correlation between the "Glacial" deposits such as those found in physiographic regions 1A, 1B, 1C, 1D, 2 and 7, and the computed  $V$  values. Region No. 7 is primarily considered to be a residual soil area, however, the "Engineering Soil Parent Material Area Map" shows a finger of surficial Illinoian drift over this area. For values of  $V$  greater than 25, the inferences are that undulating to rolling topography can be expected, such as in the "Residual" soil areas referred to as Regions 3, 4, 5, 6, 8 and 9. Areas No. 5 and 9 are both lowlands reflecting the influences of glaciation, and of the more rugged residual soil parent material areas.

A Topographic Coefficient,  $T$ , has been defined for the purposes of

Table 16

Conclusions About Terrain Quantification Factors for Physiographic Regions

Coefficient of Variation, V	Topography	Physiographic Regions	Origin
(V < 5)	Level to gently undulating	IE	Lacustrine
(5 ≤ V ≤ 25)	Gently undulating to undulating	1A;1B;1C;1D;2;7	Glacial
(V > 25)	Undulating to rolling	3;4;5;6;8;9	Residual
Where: $V = \frac{S(100)}{x}$ = Coefficient of Variation			
Topographic Coefficient, T	Topography	Physiographic Region	Origin
(T > 25)	Level to gently undulating	IE	Lacustrine
(25 ≥ T ≥ 5)	Gently undulating to undulating	1A;1B;1C;1D;5;7;9	Glacial
(T < 5)	Undulating to rolling	2;3;4;6;8	Residual
Where: $T = \frac{\text{Max. ordinate}}{\text{No. contour intervals}}$ = Topographic Coefficient			

this study as the maximum ordinate over the total number of contour intervals for the Terrain Elevation Interval Curves. The limits for these values are also arbitrarily set. "Lacustrine" deposits, such as physiographic region 1E which has level to gently undulating topography, generally have T values greater than 25. For T values less than or equal to 25 or greater than or equal to 5, gently undulating to undulating topography is implied, such as for "Glacial" deposits of Regions 1A, 1B, 1C, 1D, 5, 7 and 9. Areas No. 5 and 9 are both lowlands which have localized glacial areas and localized residual soil areas. The manner of definition of the terrain factors has an influence on the category in which these physiographic regions are placed, since they were shown in the residual soil class when considering the V values. Undulating to rolling terrain is characterized by T values less than 5. "Residual" soil areas are generally placed in this category, such as Regions 2, 3, 4, 6 and 8. Physiographic Region 2 is an exception. It is the Tipton Till Plain which is entirely glaciated, but with some localized areas of rough topography. The exception may result from the very large size of this Region. It is about three times or more larger than the others, and the greater averaging effect may have had a significant influence on the resulting T value.

#### Interpretations of Specific Quantification within Physiographic Regions

An interpretation of the results from this specific quantitative investigation for the potential use of a regional approach to highway soils considerations has been made for each physiographic region in the State and the results follow.

## Northern Lake and Moraine Region

Calumet Lacustrine Plain

The Interstate highway data show (Table 11) 55.5 miles of this class of highway, or a normalized value of 0.199 miles per square mile of the physiographic region area. When using Figure 9 as a base, 68% of the mileage traverses sands, with 21% and 9% being shown for lakebeds and young till, respectively. For the geological map (73), 96% of the mileage crosses lake sediments. Using the pedologic map (1), the soil type numbers within Regions A, B, and C comprise 76%, 20% and 4%, respectively. One can speculate whether avoiding the so-called soil problem landforms in highway planning would result in a net savings in the overall cost of the highway. The writer feels strongly that the route selection should also consider the future uses of lands adjacent to the highway right-of-way. If the highways are built through soil problem landforms, probably at a higher cost, then the cost of any construction on land adjacent to the highway will probably also be higher. This concept candidly assumes all other factors involved in the selection of a route are equal.

For the Roadway Soil Survey projects which were available, the indications from Table 12 are that cuts are non-existent for Interstate highways. Cuts for primary highways are generally less than 10 ft. deep and average about 700 ft. in length.

The Coefficient of Variation for this region was 22.5% and the Topographic Coefficient was 9.6%. Both of these values indicate gently undulating to undulating topography for a glaciated area.



Typical profiles were prepared for each significant landform encountered within this physiographic region. Statistical soil classifications were determined for each soil stratum for which the data were available. Where detailed information permitted, regression equations were determined for some of the more useful relationships between soil characteristics. The information developed for each typical profile follows. Similar information for the landforms in the other physiographic regions has been left as an exercise for future investigators.

Typical Profile No. 1. This profile represents the typical stratigraphic soil column for the dune sand landform as shown on the "Engineering Soil Parent Material Map". The ground surface in this area ranges between elevation 580 and 630 having an average of about 600.

Stratum A, as shown on Figure E-1, is the dune sand material having an AASHTO soil classification of A-3(0). Frequent deposits, pockets, layers or lenses of peat or peat and marl or other organic soils are encountered in depressions within this landform. These deposits extended to depths ranging between 15 ft and 70 ft below the ground surface. Standard moisture-density curves were determined for this deposit, along with the molded dry density vs. CBR relationship. The average maximum density ( $\gamma_m$ ) was 114.9 pcf, occurring at an average moisture content of 15.3%. Regression equations shown on Figure E-2 are  $\gamma_m = 99.749 + 1.017w$ , which proved to be significant for the linear case, and  $\gamma_m = 98.9832 + 1.2305w - 0.0113w^2$ , which proved to be significant for the quadratic case, but the addition of the second order term was not worthwhile. The 95% confidence intervals are shown on the Figure. The average maximum dry density,  $\gamma_d$ , is shown as 101.4 pcf at an average optimum moisture

content of 11.2%. On Figure E-2, the linear regression equation is  $\gamma_d = 99.517 + 0.047w$  which was shown to be not significant. Similarly, the second order quadratic equation was not significant and the addition of the second order term was not worthwhile. It is  $\gamma_d = 98.6914 + 0.2778w - 0.0122w^2$ . Average CBR values (Soaked) at percentages of the maximum dry density of 90, 95 and 100% are shown as 2.1, 6.2 and 12.2, respectively. The linear regression equation is shown as  $CBR = 0.980 \gamma_d - 87.717$ , which was shown to be significant. The quadratic regression equation is  $CBR = 166.37623 - 4.22180 \gamma_d + 0.02657 \gamma_d^2$ , which was shown to be significant, but the addition of the second term was not worthwhile. The 95% confidence intervals are also shown for these data.

Underlying the dune sand is a lakebed deposit generally associated with Glacial Lake Chicago. This deposit represents Stratum B, which has the statistical classifications of a silty clay A-6(9). Occasional pockets, layers or lenses of silty loam are encountered in this deposit, which extends to depths ranging between approximately 98 ft and 135 ft below present ground. Regression equations were determined for several relationships associated with the consolidation and shear strength properties of these sediments. The liquid limit vs. plasticity index linear regression equation is  $I_p = 0.904w_L - 12.874$ . Casagrande's "A"-Line is shown for comparison. It has the equation  $I_p = 0.73 (w_L - 20\%)$ . A linear relationship,  $C_c = 0.014w_L - 0.203$ , relates liquid limit to compression index. The relationship  $C_c = 0.009 (w_L - 10\%)$ , Reference (61, page 66) is also included on Figure E-3 for comparison purposes.

The linear relationship for standard penetration test value  $N$  vs. unconfined compressive strength ( $q_u$ ), shown on Figure E-4, is

$q_u = 0.165 N - 0.151$ . The data from (61, page 300) is shown for comparison purposes. Also on this Figure is the relationship for plasticity index ( $I_p$ ) vs. ratio of shear strength to effective overburden pressure ( $\frac{c}{p}$ ). The linear regression equation determined is ( $\frac{c}{p}$ ) =  $0.075 I_p - 0.482$ . Linear and quadratic regression equations were determined as  $\log q_u = 0.844724 - 0.037325w$  and  $\log q_u = 0.5199247 - 0.0101778w - 0.0005375w^2$ , respectively, for the natural moisture content vs. log unconfined compressive strength relationship, shown on Figure E-5. The relationship of (36, Fig. II-11) has been included for comparison. The natural moisture content vs. log standard penetration test value linear and quadratic regression equations were determined as  $\log N = 1.5908 - 0.0337w$  and  $\log N = 1.465879 - 0.023157w - 0.000205w^2$ , respectively. They are shown on Figure E-6.

Below the lacustrine deposits and extending to depths ranging between about 100 ft. and 175 ft. below existing ground, is a layer of very dense or hard glacial drift known locally as hardpan. This material is Stratum C. Very limited detailed data were available for this soil because of its high strength and low compressibility. However, a linear regression equation was determined for the natural moisture content vs. log unconfined compressive strength. It is shown as  $\log q_u = 1.6188 - 0.0651w$  on Figure E-7.

Bedrock lies below the hardpan material and is shown on Stratum D. It consists of limestone, dolomite, shale and sandstone from the Silurian and Middle Devonian Systems.

Typical Profile No. 2. The stratigraphy shown on typical profile No. 2 on Figure E-8 characterizes the soil strata for the surficial lakebed

landform. The ground surface elevation ranges between 622 and 672 feet, with an average value of about 650. A statistical soil classification of clay [A-7-6 (19)] was determined for this lakebed deposit, which extends to depths ranging between about 15 and 95 feet. The deposit has occasional pockets, layers or lenses of silty loam.

In Figure E-9 is shown the relationship for liquid limit ( $w_L$ ) vs. plasticity index ( $I_p$ ). The linear regression equation is  $I_p = 0.943w_L - 16.984$ , and Casagrande's "A"-Line is shown for comparison purposes. A linear equation for natural moisture content ( $w$ ) vs. log standard penetration test value ( $N$ ) was determined as  $\log N = 2.494 - 0.069w$ , as shown on Figure E-10. Data for standard penetration test value vs. depth were compiled and presented in Figure E-11. An average  $N$ -value line was determined, rather than a regression equation, due to the large range of  $N$ -values at a given depth.

Although detailed data were limited for this deposit, a Summary of Special Test Results was compiled and presented in Table E-3. The natural moisture content varies from 21% to 28%, the natural dry density ranges between 96 pcf and 101 pcf, the initial void ratio varies from 0.67 to 0.75, the compression index ranges between 0.14 and 0.16, and the preconsolidation stress-effective overburden stress ratio varies from more than two (higher elevation) to zero (lower elevations). The latter evidence indicates normally consolidated material except as desiccated near the surface. A moisture-density test gave a maximum wet density of 120 pcf, a maximum dry density of 102 pcf and an optimum moisture content of 17%. Results from a soaked CBR test yielded CBR values of 1.1, 1.6 and 2.1 for specimens molded at 90%, 95% and 100 % of the maximum dry

density, respectively.

A dune sand layer underlies the lakebed soils, and extends to depths varying from 30 to 102 feet below existing ground. The statistical soil classification (Stratum B) is sand [A-3(0)].

Stratum C lies below the dune sand. It extends to depths ranging from 90 to 150 feet below present ground elevation. The soils consist of glacial drift described as undifferentiated layers of clay, sand and gravel. There has been no need for detailed soil engineering information for highway design at these depths up to the present time.

Still deeper are the consolidated formations (bedrock), representing Stratum D. They consist of shale (primarily New Albany and Antrim) and limestone from the Upper and Middle Devonian Systems.

Typical Profile No. 3. The Wisconsin ground moraine landform is represented by the stratigraphic soil column shown in the profile on Figure E-12. It is associated with ground surface elevations ranging from 625 to 680 feet, averaging about 647. The Wisconsin ground moraine has a statistical soil classification of silty clay loam [A-6(11)]. Frequent pockets, layers and lenses of sand or silt are encountered within this deposit, which extends to depths ranging between about 22 and 100 feet below existing ground.

Linear and quadratic regression equations for standard moisture-density relations were determined as  $\gamma_m = 104.727 + 1.096w$  (not significant) and  $\gamma_m = 83.465 + 4.665w - 0.126w^2$  (significant, and addition of the second order term was worthwhile), respectively. The average maximum wet density was determined to be 130.1 pcf at an average moisture content



of 16.6%. Regression equations were also developed for the moisture content vs. dry density as  $\gamma_d = 104.435 + 0.061w$  (not significant) and  $\gamma_d = 86.2603 + 3.1111w - 0.1076w^2$  (significant, and addition of the second order term was worthwhile) in the linear and quadratic forms, respectively. The average maximum dry density was determined as 111.9 pcf at an average optimum moisture content of 15.6%.

Linear and quadratic regression equations were developed for compacted dry density vs. soaked CBR relationships. They are  $CBR = 0.274 \gamma_d - 23.976$  (significant) and  $CBR = 0.9913 \gamma_d - 0.0034 \gamma_d^2 - 61.6181$  (significant, but addition of second order term was not worthwhile), respectively. Average CBR values of 3.1, 5.3 and 7.4 were obtained for specimens molded at 90%, 95% and 100% of the maximum dry density, respectively. The 95% confidence intervals were determined for the above significant relationships, which are shown on Figure E-13.

The liquid limit vs. plasticity index linear regression equation was determined as  $I_p = 0.825w_L - 10.677$ . It is shown on Figure E-14 along with Casagrande's "A"-Line. A linear regression equation,  $\gamma_d = 167.172 - 3.284w_p$ , was determined for the plastic limit vs. maximum dry density relationship shown in Figure E-15. On Figure E-16 is shown a linear regression equation for standard penetration value vs. unconfined compressive strength relationship, viz.,  $q_u = 0.0875 + 0.2125 N$ . The linear regression equation,  $\log q_u = 1.3471 - 0.0548w$ , is shown on Figure E-17 for the natural moisture content vs. log unconfined compressive strength relationship. Similarly,  $\log N = 2.0966 - 0.0530w$  is the natural moisture content vs. log standard penetration test value linear relationship. It is shown on Figure E-18.

Stratum B consists of glacial drift having a soil description of sand or sand and gravel. It generally extends to depths ranging from 22 to 100 feet below the present ground surface.

An undifferentiated deposit of glacial drift consisting of layers of clay, sand, and gravel are considered to represent Stratum C. Occasionally, a hardpan layer lies above the consolidated (bedrock) formations. The soil layers generally extend to depths varying between 93 and 130 feet below existing ground. Detailed information was not available for these deposits.

Stratum D consists of shale, limestone, dolomite and sandstone from the Middle Devonian and Silurian Systems.

The ratings of highway soils considerations for landforms within this region are shown in Table 14. The major problems with the dune sand landform seem to be erosion of slopes and scour at bridge supports. Problems of settlement, predetermination of pile lengths, subgrade pumping, shrink-swell, and determination of lateral earth pressures for retaining structures appear to be the main considerations for the lacustrine landform. The maximum distribution of lacustrine deposits is 86% of the total, as shown in Table 15. The depression and stream channel soils appear to be problems whenever and wherever they occur, which is quite frequently within this region. The ground moraine landform has a minor distribution, therefore the associated problems are not considered to be major, except for subgrade pumping, and shrink and swell potential.

#### Valparaiso Morainal Area

The approximate Interstate mileage within this physiographic region is 58.7, as shown in Table 11. The area of the region is 619 square

miles, which yields a normalized Interstate mileage of 0.095 miles per square mile. Table 11 indicates, based on engineering soils mapping, that 27% and 64% of the total mileage traversed young till and moraines, respectively. From the geologic mapping, about 86% of the Interstate mileage went through end moraines and 8% crossed ground moraines. Based on the pedologic mapping, Regions A, B, C, D and F had 4, 20, 19, 49 and 8 percent, respectively, of the total Interstate mileage.

Information about cuts presented in Table 12 indicates that they will generally be less than 10 ft. in depth. However, about one of every five will range between 10 ft. and 25 ft. They will average about 850 ft. in length for Interstate and approximately 300 ft. for Primary classes of highways.

A Coefficient of Variation of 17.4% and a Topographic Coefficient of 7.8% are shown in Table 13. According to the limits set in Table 16, these values clearly indicate a glaciated area.

The anticipated soils problems shown in Table 14 are primarily confined to the stream bed or organic depression deposits which are of minor occurrence. Exceptions are the high pumping and shrink-and-swell potentials anticipated for the ground moraine and lacustrine deposits. However, the maximum distribution of lacustrine deposits is only 3% of the total area (Table 15).

#### Kankakee Outwash and Lacustrine Plain

Within this physiographic region, having an area of approximately 3,256 square miles, the total Interstate mileage is 92.8. This amounts to a normalized value of 0.029 miles per square mile of the total area, as shown in Table No. 11. Engineering soils mapping shows about 36, 30,

16, and 18 percent of the mileage traverses the porous substrata, sands, young till, and moraine landforms, respectively. The significant landforms, as defined by the geologic mapping, are lake sediments, dune sand, and valley train-outwash plain sediments, which comprised 10, 12 and 73 percent, respectively, of the total Interstate mileage. Regions A, B and C from the pedologic mapping consist of 67, 10, and 22 percent of the total Interstate mileage, respectively.

Table 12 indicates that cuttings are relatively infrequent. For Interstate highways, most cuts are expected to be less than 10 ft. deep, with one of every 10 ranging between 10 ft. and 25 ft. The cuts average about 250 ft. in length. There were no cuts encountered on the one Secondary project examined.

Terrain quantification factors in Table 13 show that (V) is 23.6 and (T) is 10.6. This is within the range set for glaciated areas in Table 16.

The highway soils considerations are quite varied. Problems expected within the lacustrine and alluvial landforms consist primarily of settlement and stability of embankments and bridge structures, although an examination of Table 14 will show other isolated problems. Table 15 indicates that the maximum distribution of lacustrine deposits within this region is 16%. Organic depression soils are again of major importance in all respects. The potential problems associated with the granular sand dune and valley train and outwash plain sediments are largely those of slope erosion and scour of bridge foundations.

### Steuben Morainal Lake Area

The data in Table 11 indicate that about 80.1 miles of Interstate highway occur within this physiographic region of approximately 3,684 square miles; which amounts to 0.022 miles per square mile. From the engineering soils mapping, about 31, 23 and 46 percent of the total Interstate mileage traversed the porous substrata, young till and moraine landforms, respectively. Based on the geological mapping, valley train and outwash plain sediments comprised 43% of the total mileage crossed, with 11, 30 and 13 percent being obtained for the ice-contact stratified drift, end moraine, and ground moraine landforms, respectively. The pedologic regions shown as A, C, D, E and F were traversed by 29, 2, 25, 3 and 41 percent of the total Interstate mileage, respectively.

Information pertaining to cuts (Table 12) indicates that soil cuts occur frequently on all classes of highway projects in this region. On Interstate highway projects about 4 of 10 cuts will be less than 10 ft. in depth, with a similar frequency ranging between 10 ft. and 25 ft., and 2 of 10 exceeding 25 ft. in depth. The Primary and Secondary project data show that most of the cuts will be less than 10 ft. in depth, but about one of four will range between 10 ft. and 25 ft. The cut length averages between about 550 ft. and 600 ft. depending on the class of the project.

The data presented in Table 13 show a Coefficient of Variation of 23.8% and a Topographic Coefficient of 8.3. This would signify that the area is glaciated, based on the limits set in Table 16.

Ratings of highway soils considerations in Table 14 show that the major problems are anticipated for the alluvium and lacustrine landforms.



Lakebeds comprise a maximum of 3% of the total physiographic region area. The main problems expected are settlement and stability of embankments and bridge structures, although other problems appear in the Table. Organic depressions and lakes occur frequently within this area and create characteristic problems. Slope erosion and scour at bridge piers are the main considerations for the alluvium and for the valley train and outwash plain landforms.

#### Maumee Lacustrine Plain

There were no Interstate highways in this physiographic unit of about 146 square miles. Roadway soil survey cut data were not available either.

A Coefficient of Variation of zero, and a Topographic Coefficient of 100% were obtained. Thus, the region is clearly within the category (Table 16) for lacustrine deposits having level to gently undulating topography.

The ratings of Table 14 indicate that the usual problems associated with alluvium, lakebed, and organic depression soils can be anticipated. These are mainly associated with the settlement and stability of embankments and bridge structures.

#### Tipton Till Plain

This physiographic region is the largest in the State of Indiana, and one might logically expect to find more Interstate mileage within this region than in any other. Table 11 indicates that this is actually the situation. Approximately 518.2 miles of Interstate highways will be built within the 13,435 square miles of the unit. Therefore, the

normalized Interstate mileage is 0.039 miles per square mile. Based on the engineering soils mapping, about 7, 65 and 21 percent of the Interstate mileage traverses the porous substrata, recent alluvium, young till, and moraine landforms, respectively. The geologic mapping indicates about 16, 9 and 73 percent of the Interstate mileage occurs within the valley train and outwash plain, end moraine, and ground moraine landforms, respectively. From the pedologic mapping, about 9, 62, 13, 10 and 6 percent of the Interstate highways traverse Regions C, E, F, G and H, respectively.

Table 12 clearly shows that a majority of the cuts are less than 10 ft. in depth. Approximately one of four cuts will range between 10 ft. and 25 ft. in depth, and about one in twenty will reach a depth of more than 25 ft. The average length of cuts is about 700 ft. for Interstate projects and approximately 500 ft. for Primary and Secondary classes of highways.

A Coefficient of Variation of 22.8% and a Topographic Coefficient of 3.7% were computed (Table 13). The value for (V) clearly indicates an area of glacial origin having gently undulating to undulating topography. However, the value of (T) suggests a residual soil area. This represents the most notable exception to the categories of Table 16.

The ratings of highway soils considerations in Table 14 indicate that the most serious problems are expected to occur within the alluvium landform. These problems are primarily associated with settlement and stability of embankments and bridge structures. Of course, the normal considerations with respect to landforms consisting of primarily granular soils or organic deposits can be anticipated. Fortunately, the occurrence

of organic deposits and lakebeds within this physiographic unit is very small; Table 15 indicates a 1% maximum. The pumping and the shrink-swell potential of the ground moraine landform soils, as well as the occurrence of some strip and shaft mines are additional considerations. The latter are limited to the coal measures of the Pennsylvanian System found in the western part of this region. Some loess is also found in the western portion of the area.

#### Dearborn Upland

The approximate total Interstate mileage within this region of about 1,829 square miles, is 33.5. When normalized, this amounts to 0.018 miles per square mile. These highways traverse the old drift and the interbedded limestone and shale landforms at a frequency of 66 and 31 percent, respectively, when considering the engineering soil boundaries. Based on the geologic mapping, about 13 and 87 percent of the Interstate highways occur within the valley train and outwash plain and the Illinoian drift landforms, respectively. The pedologic mapping indicates that about 16, 69 and 15 percent of the total Interstate highways mileage traverses Regions H, J, and K, respectively.

Information related to cuts within this region as shown in Table 12 is somewhat misleading. The one Interstate project for which information was available occurred in the Ohio River flood plain. It had no cuts, but this is by no means typical of most of this region. The cut data for the Primary class of highways is somewhat more realistic, although it is felt that one should anticipate deeper cuts more frequently than shown. In addition, weathered rock and rock will be encountered frequently in cuts made within this physiographic unit. The length of

cuts is shown to average about 300 ft.

The Coefficient of Variation was computed as 29.8% and the Topographic Coefficient was 2.4%. Either method for describing the terrain places this physiographic unit in the residual origin category. Undulating to rolling terrain is indicated, as shown in Table 16.

Ratings of highway soils considerations appear in Table 14. The residual soil areas which are underlain by interbedded limestone and shale are historically "bad-actors". Existing slopes are relatively flat in this region, indicating materials of limited in-situ shear strength. Experience has shown that this region is the most landslide susceptible one in the State. Side-hill cut-to-fill situations have proven to be particularly troublesome.

#### Muscatatuck Regional Slope

A normalized Interstate mileage per unit area of 0.014 results from the 23.9 miles of Interstate highways which traverse this region of approximately 1,653 square miles (Table 11). The young till, moraines and old drift landforms, as defined by engineering soils mapping have about 48, 23 and 27 percent, respectively, of the total Interstate mileage. The geologic mapping indicates that 7, 18, 60 and 15 percent of the mileage crosses the valley train and outwash plain, end moraine, ground moraine, and Illinoian drift landforms, respectively. Regions E, F, and J as defined by pedologic mapping are traversed by 33, 49 and 18 percent of the total Interstate mileage, respectively.

The cut data of Table 12 show that soil cuts are generally less than 10 ft. in depth. The occurrence of weathered rock and rock in cuts is expected in about two of every five. These rock cuts have more than

10 ft. of rock above proposed grade. The lengths of cuts average about 900 ft. and 450 ft. for Primary and Secondary highways, respectively.

Coefficients of Variation and Topography, as shown in Table 13, were estimated as 25.8 and 3.1 percent, respectively. This tends to indicate a residual soil area having undulating to rolling terrain (Table 16).

The ratings of highway soils considerations in Table 14 show that the materials within this physiographic region are, for the most part, average in quality and anticipated behavior. A normal concern is reflected in the Table for such problems as pumping and shrink and swell potential (for the Wisconsin ground moraine and the residual soil landforms); erosion and scour (within the valley train landform); and settlement and stability considerations for embankments and bridge structures (within the alluvium and lacustrine landforms). The maximum distribution of lacustrine deposits as a percentage of the total area is shown as 13 in Table 15.

#### Scottsburg Lowland

There is approximately 87.9 miles of Interstate highway within this region of 1,493 square miles. This yields a normalized quantity of 0.059 miles per square mile of area. The engineering soils mapping indicates that 6, 19, 6, 45 and 16 percent of the Interstate highways within this unit traverse the porous substrata, lakebeds, young till, old drift and sandstone (with some shale) landforms, respectively. From the geologic mapping about 17, 33, 40 and 7 percent of the Interstate mileage occurs within the lakebed, valley train and outwash plain, Illinoian drift, and bedrock landforms, respectively. Based on the

pedologic mapping, Regions H, J, L, and O are traversed by 29, 50, 17 and 4 percent of the Interstate mileage.

The cut information in Table 12 is limited to Interstate projects. The data show that most of the cuts in soil will be less than 10 ft., with about one of five ranging between 10 ft. and 25 ft., and one of twenty reaching a depth of 25 ft. or greater. It is likely that one of ten cuts will encounter weathered rock above proposed grade and one of twenty will have rock above proposed grade. These cuts will generally have more than 10 ft. of rock above proposed grade. The average length of cut is about 950 ft.

In Table 13 the Coefficient of Variation is shown as 25.3% and the Topographic Coefficient is 5.0%. The indications from Table 16 are that this is an area of residual origin having undulating to rolling terrain. However, the  $T = 5.0\%$  value is marginal with a glacial origin category. This is logical, since much of the northern sector has felt the effects of glaciation.

The comments for the problem ratings shown in Table 14 are very similar to those made previously for the Muscatatuck Region Slope. Lakebeds and alluvial sediments once again create the greatest challenge. The distribution of lacustrine deposits is relatively large, at 12% of the total area. The area has a moderate landslide susceptibility rating.

#### Norman Upland

There are 5.6 miles of Interstate highway within this physiographic region, as shown in Table 11. The area is approximately 1,233 square miles, which accounts for a normalized Interstate mileage of 0.005 mile



per square mile. When considering the boundaries of the engineering soils map, all of the Interstate mileage is to be built within the sandstone (with some shale) landform. Based on the geologic mapping, all of the Interstate highways traverse the bedrock landform. The pedologic map Regions shown as L and M account for 29 and 71 percent of the total Interstate mileage, respectively.

The Coefficient of Variation is 26.5% and the Topographic Coefficient is 2.9%, as shown in Table 13. Using the criterion as outlined in Table 16, the area is indicated to be of residual origin having undulating to rolling topography.

Excavation or cut information shown in Table 12 indicates in general that as the class of the highway decreases (Interstate to Secondary), the number of soil cuts increase. About one of six cuts on Interstate highways is in soil, with a frequency of approximately one of three and eight of ten applying for Primary and Secondary routes. In general, about one half of the soil cuts are less than 10 ft. in depth, with the remainder ranging between 10 ft. and 25 ft. Not much weathered rock is encountered in the cuts. Thus, the cuts that are not completely in soil will be in bedrock, and the indications are that most of them will have more than 10 ft. of rock above proposed grade. It is evident that as the class of highway decreases, so does the percentage of rock cuts with more than 10 ft. of rock above proposed grade. The data also show that the deepest cuts in the state occur within this region. This fact is undoubtedly the result of having to provide an acceptable grade from the Scottsburg Lowland, through the Knobstone Escarpment and onto the higher ground in the Norman Upland. The average lengths of cut within

this region are about 1100, 750 and 500 ft. for Interstate, Primary and Secondary classes of highways, respectively.

The ratings of highway soils considerations shown in Table 14 indicate that the usual problems are expected within the lacustrine and alluvium landforms. According to Table 15 the maximum distribution of lacustrine deposits within this area is 13%. The only significant problems anticipated within the residual soils are those of pumping, and shrink and swell of the subgrade soils.

A system of geologic or structural faulting is associated with the bedrock within this region. The most famous of these faults in Indiana is the Mt. Carmel, which trends in a north-south direction. Naturally there are evidences of cross faulting also. The indications are that this fault system has been inactive in recent times.

#### Mitchell Plain

The approximate Interstate highway mileage within this region is 22.2. Table 11 also shows that the area is about 1,295 square miles and that normalizing these values results in a value of 0.017 miles per square mile. The Interstate highways within this region traverse, at a rate of 46 and 54 percent, respectively, the old drift and limestone landforms (5). From (73), about 37 and 63 percent of the Interstate highways cross the Illinoian drift and bedrock landforms. Regions I, K, and M as defined on (1) are traversed by 35, 14 and 51 percent of the Interstate mileage, respectively.

Table 12 shows that about two of every three cuts are excavated in soil. For Interstate highways, one of four cuts in soil will be less than 10 ft. in depth, one of three cuts should be between 10 ft. and

25 ft. in depth, and one of ten soil cuts will be greater than 25 ft. in depth. The data for Secondary projects indicate that about one of two cuts will be less than 10 ft. in depth in soil, with one of six cuts ranging between 10 ft. and 25 ft. depths, and one of about fifty cuts will be greater than 25 ft. in depth. About one of every three cuts will encounter bedrock. Weathered rock was not encountered within this region. Of these rock cuts, one of two cuts will have more than 10 ft. of bedrock above proposed grade. The data also indicate that some of the deeper cuts within Indiana have been made within this region. Average cut lengths of approximately 1050 ft. and 550 ft. are shown for Interstate and Secondary projects, respectively.

The Coefficient of Variation value as shown in Table 13 is 19.3% and the Topographic Coefficient is 5.2%. In each instance, the values tend to indicate an area of glacial origin having gently undulating to undulating topography. Ordinarily, one would think of this region as residual, however, the engineering soils map shows a thin belt of Illinoian drift extending its length and capping the (primarily) limestone bedrock.

Ratings of highway soils considerations, as shown in Table 14, indicate that sinkholes and solution channels within the limestone bedrock is one of the predominate problems. The residual soils developing from this parent material are considered to be some of the poorest for subgrades in the state. The usual concern is felt for the alluvium and lacustrine landforms. The maximum distribution of lacustrine deposits shown in Table 15 is 6 percent of the total area. This area is considered to have a landslide susceptibility rating of low to moderate.

## Crawford Upland

The Interstate highway mileage occurring within this region of 2,432 square miles is 37.7, or 0.016 miles per square mile (Table 11). Of this total, about 12, 18 and 61 percent traverse the lakebed, old drift and limestone-sandstone-shale landforms, respectively (5).

For the boundaries defined by the geological mapping, about 6, 20 and 74 percent of the Interstate highways cross the valley train and outwash plain, Illinoian drift and bedrock landforms, respectively. The Regions B, I, K, L and M as shown on (1) are traversed by 6, 15, 52 and 2 percent of the total Interstate mileage, respectively.

A Coefficient of Variation is shown as 27.2% in Table 13 and the Topographic Coefficient is 3.15. This tends to indicate conclusively that the area is of a residual nature having undulating to rolling (in some cases even rough) topography.

The cut data shown in Table 12 have the greatest variety of any region within the State. About one of three cuts will be in soil for Interstate highways and about eight of nine for Secondary projects. Of these soil cuts, about one half will be less than 10 ft. in depth, with the rest ranging between 10 ft. and 25 ft. An occasional soil cut greater than 25 ft. in depth was encountered on Interstate highways. Weathered rock was encountered in one of every four cuts. Bedrock was encountered in about one of two cuts for Interstate highways, and one of nine cuts for Secondary routes. About two thirds of the cuts in which rock was encountered, on Interstate projects, had more than 10 ft. of rock above proposed grade. Some of the deeper cuts in this State will be made in this physiographic region. The cut lengths averaged about 900 ft. and 650 ft. for Interstate and Secondary classes of highways, respectively.

Table 14 indicates that the most significant problem to be anticipated is the stability of slopes. This area has one of the highest landslide susceptibility ratings in the State. Some problems with pumping, and shrink and swell of the subgrade are expected for the residual soils. Once again, the lacustrine and residual soils will provide the greatest challenge. Table 15 shows a maximum distribution of lacustrine deposits of 9 percent of the total area.

#### Wabash Lowland

This region has the second largest area in Indiana, viz., 4,937 square miles, as shown in Table 11. The approximate Interstate mileage is 99.0, which yields a normalized value of 0.020 mile per square mile. Based on (5), about 21, 17, 26 and 33 percent of the Interstate mileage traverses the lakebed, old drift, loess, and interbedded shale-sandstone landforms, respectively. The percentages of Interstate highways traversing the lakebed, valley train and outwash plain, Illinoian drift, and bedrock landforms based on (73), are about 12, 14, 30 and 44, respectively. From (1), about 20, 19, 32, 7, 8 and 14 percent of the Interstate highway mileage crosses Regions B, I, L, N, O and P, respectively.

The Coefficient of Variation is 26.0% and the Topographic Coefficient is 7.2%, as shown in Table 13. These values lead to conflicting conclusions about the origin of this region based on the limits of Table 16. The value for (V) indicates an area of residual origin and the value of (T) tends to show a glacial influence. Actually, there is logic in these descriptions, since the northern portion of this residual area has felt the influences of glaciation.

Data included in Table 21 show a variety of excavation information. About seven of nine cuts on Interstate highways are in soil, about one of every two cuts being less than 10 ft. in depth and most of the remaining ranging between 10 ft. and 25 ft. An occasional cut of more than 25 ft. depth is encountered. For Primary routes, about five of six cuts are in soil. Only one of five cuts ranges between 10 ft. and 25 ft. in depth, with the remainder being less than 10 ft. The data for Secondary projects is not significant since it represents only one project. Weathered rock will be encountered in cuts at an average rate of one in five, and rock will be encountered at an average rate of about one in twenty. For those cuts in which rock is encountered above proposed grade, about half will have more than 10 ft. of rock above this grade. Average cut lengths were determined to be 750 ft. and 300 ft. for Interstate and Primary highways, respectively.

The ratings of highway soils considerations (Table 14) indicate several problems peculiar to this physiographic region. Many strip and shaft mines are excavated within the formations of the Coal Measures Series of the Pennsylvanian System. These are potentially hazardous foundation areas. Loess deposits and their accompanying problems are also of major importance. The usual considerations relative to granular deposits and residual clays are evident in the Table. Alluvial and lacustrine deposit problems are also reflected in the Table. Lacustrine deposits are abundant at 36% of the total area (Table 15). Instability of slopes is given a "moderate" rating.



Summary For Specific Quantification of Significant  
Factors Influencing a Regional Approach to  
Highway Soils Considerations

As stated previously, the significant factors influencing a regional approach to highway soils considerations are the geologic origin and complexity of parent materials (or landforms), topography, and the texture of the parent materials (particularly the percentage of the clay fraction). This section on "Specific Quantification" presents an approach for handling these factors in some detail.

1. The Interstate highway mileage within each landform or numbered soil area was determined as a percentage of the total Interstate mileage within the physiographic region and is presented in Table 11. These data tend to answer the question, "What landforms, soil types or soil type numbers do our existing or designed highways traverse?" With this information, one can speculate as to the nature of the soils considerations and whether their magnitudes could be lessened by route relocation to traverse more desirable landforms. Economics is the criterion, and both initial cost and maintenance costs, should be included. Development of this information for Primary and Secondary highway routes was left as an exercise for future investigators.

2. One can make some very effective inferences about the nature of the terrain, the adequacy of standard design backslopes and whether rock excavation will be required on a given project, if he has a summary of the cut information for other projects in the same region. Therefore, a detailed study was made of the proposed cuts in the consultants Roadway Soil Surveys. Numerous cut statistics have been included in Table 12. The inferences are: the lesser number and shallower depth of cuts

indicate more level terrain; the shallower average depth of cuts implies more stable backslopes, and the frequency of rock cuts is uniquely related to the physiographic region. The bedrock information is especially useful south of the Wisconsin Glacial Boundary, where thickness of drift maps are not applicable.

3. Several terrain descriptors were determined for the Terrain Elevation Interval Curves presented in Appendix B. These are the "Coefficient of Variation,  $V(\%)$ ", a statistical tool, and the Topographic Coefficient,  $T(\%)$ , defined for the purpose of this study. These values were calculated for the curves obtained for each physiographic region and are presented in Table 13. The significance and usefulness of these results have been shown in Table 16, entitled "Conclusions about Terrain Quantification Factors for Physiographic Regions". The table shows that limits set for these values can be used to predict the general soil origin.

4. To demonstrate some degree of uniformity or frequency of occurrence for the soil types encountered within each significant landform within a physiographic region, "Typical Profiles" were developed for the Calumet Lacustrine Plain. The data for the physical properties of the soils comprising each significant landform were subjected to statistical methods and procedures in an attempt to characterize each significant layer or stratum within each typical profile. The typical profiles, pertinent relationships examined, and the regression equations developed have been included in Appendix E. Development of similar information for landforms in other physiographic regions would be most useful, but would be a major undertaking. All such summaries should be continually updated as more

information becomes available.

5. Ratings of highway soil considerations for landforms within physiographic regions in Indiana are presented in Table 14. The writer considers that this information is potentially quite valuable for practicing soils engineers, inexperienced in this geographical location. The usefulness of these data could be expanded, if other practicing soils engineers (experienced in this locale) were to offer constructive criticisms, and if their thoughts and experiences were to be reflected in a modified presentation. These ratings are primarily useful in the "Preliminary Studies" phases of highway planning, route location and design. One must always keep in mind that: (a) these ratings are generalizations within a landform, and (b) they reflect the present standards, policies and procedures used by the Indiana State Highway Commission for the design and construction of modern highway facilities. It is emphasized that detailed information is needed at a specific location before final decisions are made. The information in this study may influence a detailed investigation, but does not replace it. Only if a partial study of a project were to reveal conditions extremely similar to those developed within this investigation, and if there were sufficient data available in this study to lead to statistically sound conclusions, may a complete detailed study be judged unwarranted for that particular project. This decision should always be made by a competent, experienced soils engineer.

GENERAL RELATIONSHIP BETWEEN THE PRESENT STANDARDS,  
POLICIES AND PROCEDURES AND A REGIONAL  
APPROACH TO HIGHWAY SOILS CONSIDERATIONS

The general relationship between the present Indiana State Highway Commission's standards, policies and procedures with respect to soil and foundation engineering and the topic of this investigation has been studied. The intent of this phase of the study is to offer suggestions which will hopefully result in a more rational or economical approach to some of these matters. All conclusions represent the personal views of the writer (based on his experience), and they should not be interpreted necessarily to represent the views of other personnel of the Indiana State Highway Commission.

Flow Diagram for Office Study Prior to  
Performance of Roadway Soil Survey

As pointed out by McKittrick (48), a thorough review of the relevant literature for the various disciplines of physiography, topography, remote sensing, geology, pedology and soils engineering need not increase the total cost of roadway soil surveys. In addition, this preliminary research makes potential problem areas more evident, and results in a desirable redistribution or concentration of survey effort. Since funds for the performance of a soil survey are limited, it is important to distribute them carefully, giving greatest attention to those areas having the greatest potential problems.

An organized or systematic approach to the office study has been presented in Table 17 entitled, "Flow Diagram For Office Study Prior to Performance of Roadway Soil Survey". The flow diagram attempts to show the information that is available in Indiana for the various disciplines of interest, starting at a small scale representing the national level and expanding to a larger scale representing the county or possibly the 1:24,000 quadrangle level. Thus, given a proposed project location, one can search through the literature at the various levels, concluding with the rather specific information on mechanical properties and potential problems from Bulletin 87 (5), from the four Soil Conservation Tables shown in Appendix A, from Table 14 included in this study, and from data similar to that presented in Appendix E.

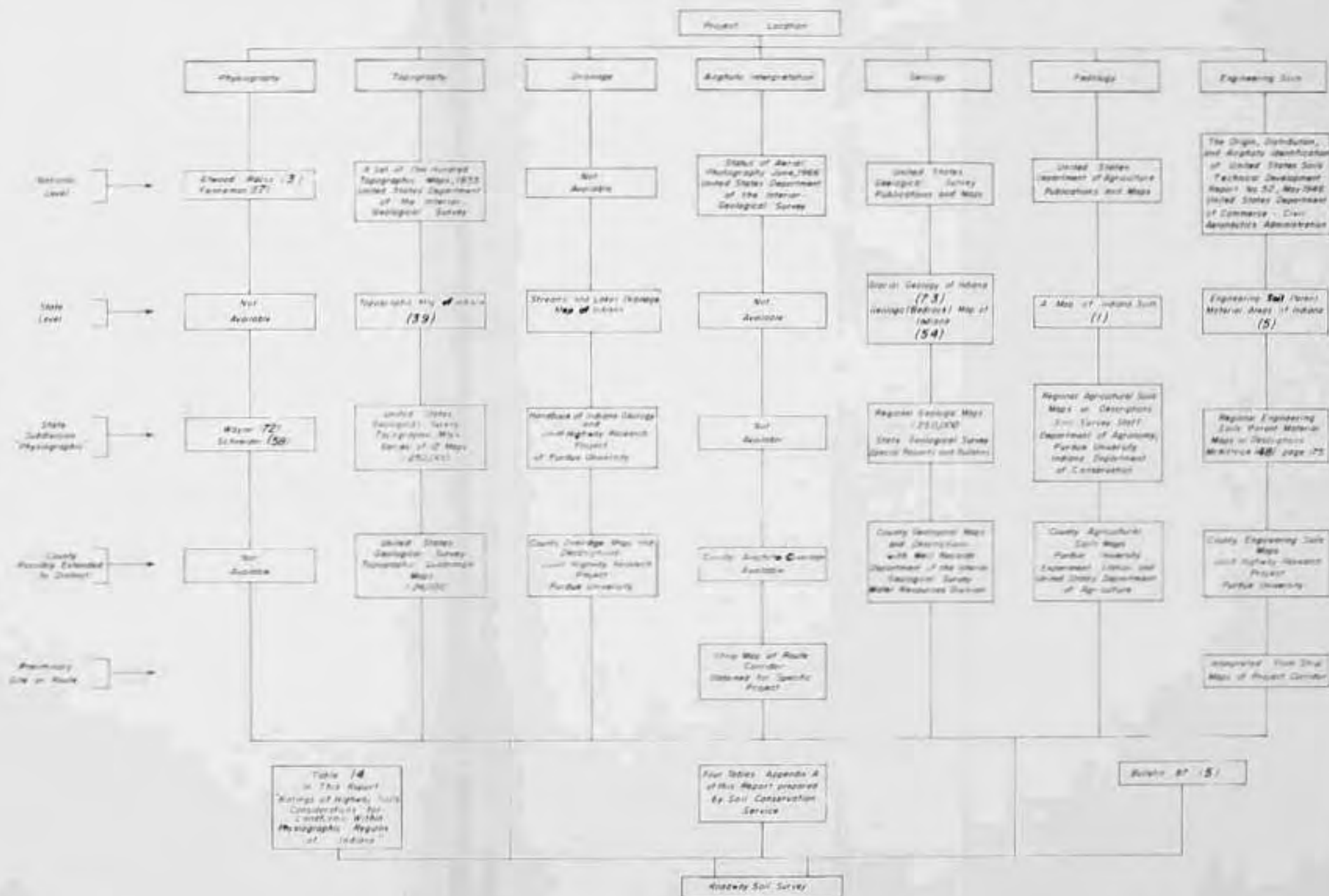
At this point, the soils engineer has the tools and the background to establish a realistic boring plan. This can best be accomplished by walking the proposed alignment, and establishing the actual boring locations based on the proposed lines, grades and slopes, the existing terrain, and the background office study information. This should result in the most economical roadway soil survey, assuming the services of a competent experienced soils engineer.

#### Possible Beneficial Modifications of Present Roadway Soil Survey Procedures

The present roadway soil survey procedures have been generally providing adequate information for the proper design of modern highway facilities. The following are a few areas in which some improvement and/or economies might be realized:

1. The present "Requirements for Roadway Soil Survey and Foundation

TABLE 17  
 FLOW DIAGRAM  
 for  
 OFFICE STUDY PRIOR TO PERFORMANCE OF ROADWAY SOIL SURVEY





Borings for Structures" calls for soundings generally at 100 ft. intervals at various offsets within the proposed construction limits: (a) when rock is encountered near or above proposed grade in cuts, and (b) when unstable materials such as peat, marl and/or muck are encountered under proposed embankments. The purpose of these soundings is to determine the quantity of rock excavation or peat excavation required on the project. Some of the surrounding States are already employing seismic refraction or electrical resistivity geophysical methods for this purpose, claiming both economy and adequate precision. After limited experience with such techniques, Indiana might reach similar conclusions.

2. In areas and deposits where it is difficult to obtain undisturbed samples of clayey soils, it may be advisable to perform field vane shear tests. At times, it is more economical to perform this test in the field, than to obtain and test good quality "undisturbed" samples.

#### Possible Benefits of Additional Soils Engineering Services

There is a need for the services of soils engineers in almost all Divisions and Departments within the Highway Commission. This need is not always apparent. For example, where soil-structure interaction is involved, the structural design engineer or the design project engineer, in the Division where the particular problem arises, makes the engineering decisions. In such situations there is actually a dual responsibility. If the planning, design or project engineer does not elect to consult with a soils engineer, portions of the project may be underdesigned, making it potentially unsafe, or possibly grossly overdesigned, making it uneconomical. The following are circumstances in which a soils engineer's opinion should be sought and considered before any final

decisions are made.

1. The soil condition along a proposed route is one of the factors to be considered in the planning stage of any highway. While in many cases this factor is admittedly overshadowed by others, there will be projects where minor changes in alignment make it possible to miss a "peat-hole" or shorten the length of highway traversing a troublesome lakebed or alluvial deposit. While the Division of Planning does not need the full-time services of a soils engineer, such services are frequently of value.

As an aid in determining when soils advice is needed, it would be advisable for the Planning Division to plot alternate proposed routes on the County Engineering Soils Maps prepared at Purdue University, as a part of the Joint Highway Research Project. It may also be worthwhile to view the information of Table 14 in conjunction with these engineering soils maps.

2. For any structure, there are soils considerations associated with: the interaction between the soil and the structure, the stability and settlement characteristics of the soil around or under the structure, and the long range performance of the structure. Such considerations as the: type of foundation to be used (footings, piles, etc.), predetermination of pile lengths, negative skin friction on piles, determination of lateral earth pressure on retaining walls, and earth pressures on culverts under high fills, to mention a few, require the judgement of a soils engineer. Once again Table 14 should be helpful in making preliminary judgements relating to these considerations.

It is conceivable that the Division of Design could justify the

employment of soils engineers for this purpose, however, it may be more realistic to consult with a soils engineer, whether he be a private consultant or a member of another department within the Indiana State Highway Commission. Data in a form similar to that included in Appendix E would be most useful, if it were available for all landforms within the State, or at least for the so-called problem landforms. Typical Profiles would be most helpful in the preliminary phases of structural design.

3. The soils considerations related to roadway design are many and varied and require the judgement of an experienced soils engineer. The details of the roadway soil survey depends: on the homogeneity of the landforms traversed (the First Degree for Measure of Uniformity Ratings in Table 8 may be useful for this purpose), on the variability of landforms within the specific project area, on the variability of the soil types within the landforms to be traversed, and on the experience obtained on previous projects through these landforms. The data in Table 14 would be helpful but the most useful data would be like that included in Appendix E. The typical profiles and values for the various relationships for the strata within each typical profile would reflect: past experiences with these landforms, the extent and detail of soils information which was required on previous projects, the amount of information which has been accumulated to establish any given relationship, as well as providing average parameters for preliminary computations. Thus, there is a real need for the development of information similar to that presented in Appendix E, for many landforms within the physiographic regions of Indiana, concentrating on the suspected or known problem landforms.

4. In the design of foundations for highway signs or lighting facilities, the soil-structure interaction is somewhat complex, and consultation with a soils engineer is recommended.

#### Some Comments on the Cost of Roadway Soil Surveys

A study of the cost of roadway soil survey projects in Indiana has been made, and the results are included in Table 18. The total average cost per mile for surveys performed throughout the entire state is \$2,430. The minimum average cost per mile was \$1,430 in the Scottsburg Lowland, with a maximum of \$5,040 occurring in the Steuben Moraine Lake Area. It is concluded that one of the main reasons for the large difference in average costs per physiographic region is the need for soundings for peat or rock excavation. A portion of this differential would probably disappear if geophysical methods were substituted for the soundings.

Additional economies would probably result from the acceptance of procedures and recommendations of this study. In areas where relative uniformity or homogeneity has been demonstrated (by sufficient data), it is reasonable to reduce the detail of a soil survey. On the other hand, in areas having complex conditions and/or a limited data bank, the present course should probably be continued, pending the accumulation of sufficient data. As such data begin to show definite trends in uniformity or homogeneity, deviation from the present procedures is warranted.

Table 18  
Summary of Cost of Roadway Soil Survey Projects

Physiographic Region	Interstate				Primary				Secondary				Urban				Average Cost (\$) per Mile
	Number of Projects	Total Cost (\$)	Number of Miles	Cost (\$) per Mile	Number of Projects	Total Cost (\$)	Number of Miles	Cost (\$) per Mile	Number of Projects	Total Cost (\$)	Number of Miles	Cost (\$) per Mile	Number of Projects	Total Cost (\$)	Number of Miles	Cost (\$) per Mile	
1. Northern Lake and Moraine Region																	
A. Calumet Lacustrine Plain	1	9,970	6.3000	1,580	2	15,830	8.0500	1,970	-	-	-	-	3	14,110	5.3863	2,620	2,020
B. Valparaiso Morainal Area	2	25,690	14.0530	1,830	-	-	-	-	1	12,830	1.7000	7,550	-	-	-	-	2,450
C. Kankakee Outwash and Lacustrine Plain	6	55,960	27.9350	2,000	2	15,530	11.3000	1,370	1	2,310	0.9400	2,460	1	5,330	3.7000	1,440	1,800
D. Steuben Morainal Lake Area	2	55,880	9.3500	5,980	3	117,140	24.0000	4,880	2	48,610	10.6400	4,570	-	-	-	-	5,040
E. Maumee Lacustrine Plain	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2. Tipton Till Plain	47	462,380	266.640	1,730	13	111,670	71.7800	1,560	6	20,970	12.6700	1,660	4	17,860	10.2260	1,750	1,700
3. Dearborn Upland	1	12,330	3.0500	4,040	3	18,140	7.8400	2,310	-	-	-	-	-	-	-	-	2,800
4. Muscatatuck Regional Slope	-	-	-	-	1	14,170	4.0000	3,540	2	5,960	4.3600	1,370	1	3,540	1.0750	7,300	2,510
5. Scottsburg Lowland	3	20,120	14.1000	1,430	-	-	-	-	-	-	-	-	-	-	-	-	1,430
6. Norman Upland	1	34,830	5.1810	6,720	2	49,350	12.8540	3,840	2	10,060	3.6760	2,740	-	-	-	-	4,340
7. Mitchell Plain	4	97,590	10.6330	3,190	1	17,110	5.4000	3,170	4	78,040	28.8000	2,710	-	-	-	-	2,970
8. Crawford Upland	5	219,160	40.2800	5,440	-	-	-	-	1	8,320	5.0000	1,660	-	-	-	-	5,020
9. Wabash Lowland	13	249,860	91.5850	2,670	9	79,400	38.6750	2,050	1	9,020	9.0000	1,000	1	28,730	9.4750	3,030	2,430

Total Average Cost per Mile = \$ 2,430



Summary of the General Relationship Between  
Present Standards, Policies and Procedures  
and a Regional Approach

The general relationship between the present State Highway Commission's standards, policies and procedures as related to soil mechanics and foundation engineering and a regional approach to highway soils considerations in Indiana has been studied, and is summarized below.

1. A flow diagram for office study prior to performance of a roadway soil survey has been developed and is included as Table 17. Such a thorough review of the available literature for the various disciplines of physiography, remote sensing, geology, pedology, as well as relevant previous engineering studies, can lead to a saving in the cost of roadway soil surveys, or to a redistribution or concentration of efforts in the areas of primary interest, e.g., the problem landforms.

2. Several modifications of present roadway soil survey procedures might prove beneficial.

Currently, soundings are made, using standard drilling procedures, to determine the amount of rock excavation in cuts or to determine the amount of peat excavation under embankments. The use of geophysical equipment could lead to a net savings in the cost of performing roadway soil surveys, as reported by some of the surrounding states. It has been suggested that the State of Indiana gain experience using this equipment.

It is recommended<sup>3</sup> that the field vane shear test be employed in fine-grained deposits where it is difficult to obtain undisturbed



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It is recommended<sup>3</sup> that the field vane shear test be employed in fine-grained deposits where it is difficult to obtain undisturbed

samples. It can be more economical to perform this test in the field, than to obtain and test undisturbed samples of certain soils.

3. Ways in which additional soils engineering services might be beneficial have been studied and suggestions follow.

The soils along a proposed route should be a planning stage factor, even though this factor is properly overshadowed by others in many cases. As an aid in determining when the services of a soils engineer should be sought, it would be advisable for the planning department to plot alternate proposed routes on the County Engineering Soils Maps prepared at Purdue University. It may also be worthwhile to make available the information shown in Table 14 for use in conjunction with these engineering soils maps.

For any structure there are considerations associated with: the interaction between the soil and the structure, the stability and settlement characteristics of the soil around or under the structure, and the long range performance of the structure. Such considerations as the type of foundation to be used (footings, piles, etc), predetermination of pile lengths, negative skin friction on piles, determination of lateral earth pressure on retaining walls, and earth pressures on culverts under high fills, to mention a few, require the expertise of a soils engineer prior to making any final decisions. Once again Table 14 should be helpful in reaching preliminary judgements. Compilation of data and interpretation of this data as in Appendix E would be most useful, particularly for the so-called problem landforms. Typical Profiles would be very helpful in the preliminary phases of structural design.

The highway soils considerations related to design are many and varied, and require the judgement of experienced soils engineers. The detail required for a roadway soil survey should be based (at least to some extent): on the homogeneity or heterogeneity of the landforms traversed (see First Degree for Measure of Uniformity Ratings in Table 8), on the variability of landforms within the area, on the variability of the soil types within the landforms to be traversed, and on the past experience obtained on previous projects constructed through these landforms. The data in Table 14 would be useful for this purpose, but the most useful data would be in the form of that included in Appendix E. The typical profiles and various relationships for the strata within each typical profile would reflect: past experiences with these landforms, the extent and detail of soils information which was required on previous projects, and the amount of information which has been accumulated to establish any given relationship. In addition, it would provide average parameters for initial preliminary computations. Thus, it would seem to be quite evident that there is a real need for the development of information similar to that presented in Appendix E for all landforms, or at least for the suspected problem landforms.

In the case of foundations for highway signs or lighting facilities, the soil-structure interaction is somewhat complex. Thus, the traffic engineers would want to consult with a soils engineer prior to making any final decisions about such foundations.

4. A study has been made of the average costs of roadway soil surveys and their variation for the physiographic regions of Indiana. Table 18 indicates that the total average cost per mile is \$2,430. The

minimum average cost per mile was \$1,430 in the Scottsburg Lowland with the maximum of \$5,040 occurring in the Steuben Morainal Lake Area. It is concluded that one of the main reasons for the large difference in average costs between physiographic regions is the need for soundings where peat or rock excavation is anticipated. Real economies could result if the geophysical seismic and/or resistivity methods were accepted for use in Indiana.

Additional economies would probably result from the procedures established in this study, if the complete state-wide information is developed as suggested. In areas where uniformity or homogeneity has been demonstrated (and by means of abundant data), it is reasonable to schedule less detail in the soil surveys. On the other hand, in areas having complex conditions and a limited data back log, the present standards should be continued. If these data begin to show definite trends in uniformity or homogeneity, deviation from the present roadway soil survey procedures becomes logical.

## CONCLUSIONS AND RECOMMENDATIONS

1. The Physiographic Subdivision Approach outlined in this study can lead to meaningful and worthwhile implications and conclusions for use in the preliminary stages of planning, route location and design of modern highway facilities in the State of Indiana.

2. To increase the usefulness of this approach, a further subdivision of the physiographic units shown on Figure 1 is recommended. The landforms or Engineering Soil Parent Material Areas shown on Figure 9 (5), seem to define areas within which one can indeed generalize as to the class and severity of highway soil problems with which he must cope.

3. The significant factors influencing a regional approach to highway soils considerations are the geologic origin and complexity of parent materials (landforms), topography, and the general texture of the parent materials (particularly the magnitude of the clay fraction).

4. Methods and procedures presented in the "Summary for Generalized Quantification of Significant Factors Influencing a Regional Approach to Highway Soils Considerations", page 81, provide a useful means for generally quantifying the factors of geologic origin and complexity of parent materials (landforms), and topography. Data developed in this phase of the study, and related to the frequency of occurrence of landforms, are the basis for what has been defined as the first dimension or degree for the Measure of Uniformity within physiographic regions.

5. The methods and procedures presented in the "Summary for Specific Quantification of Significant Factors Influencing a Regional Approach to Highway Soils Considerations", page 140, provide a useful means for specifically quantifying the three significant factors of Item 3. Data developed in this phase of the study, and related to the frequency of occurrence of soil types within landforms, are the basis for what has been defined as the second and third dimensions or degrees for the Measure of Uniformity within physiographic regions. The typical profiles and regression equations for pertinent relationships which were developed for landforms within the Calumet Lacustrine Plain physiographic region, and which are included in Appendix E, could be a valuable catalog of soils experiences. If these relationships were developed for the significant landforms within each physiographic region, it could lead to greater economy in the performance of soil and foundation investigations, or at least a redistribution or concentration of any efforts to the known so-called problem landforms.

6. Presented in Table 14 are the "Ratings of Highway Soils Considerations for Landforms within Physiographic Regions in Indiana". The writer considers this information as having the greatest potential value and use for soils engineers inexperienced in this geographical location. The principal usefulness of these ratings is in preliminary studies related to highway planning, route location and design. This usefulness would be expanded several fold by the constructive criticism of other experienced soils engineers in this locality.

7. The writer feels that if the methods presented and the suggestions made in the "Summary of the General Relationship Between the



Present Standards, Policies and Procedures and a Regional Approach to Highway Soils Considerations in Indiana", were investigated and hopefully put into use, a benefit would result. This benefit would be in the form of economy and in a more rational approach to soils considerations in the various stages of planning, route location and design.

Any statements and conclusions made in this study represent the personal views of the writer based on his experience, and they should not be interpreted necessarily to represent the views of other personnel of the Indiana State Highway Commission.

## RECOMMENDATIONS FOR FURTHER STUDY

1. Typical profiles and regression equations for pertinent relationships should be developed for many of the landforms within the various physiographic regions in the State of Indiana. This information will be an invaluable file of experiences for soils engineers inexperienced in this geographical locale.

2. The information under Item 1 should be periodically up-dated by the incorporation of subsequent data. The greater amount of data should result in conclusions which are more statistically sound.

3. It is recommended that other data developed in this study using the results of completed roadway soil surveys and included in Tables 3, 4, 5, 7 12 and 18 be periodically up-dated as additional information becomes available.

4. Similar data to that shown in Table 11 should be developed for Primary and Secondary highways.

5. Table 14 should be reviewed and constructively criticized by experienced soils engineers, thus increasing its usefulness.

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APPENDIX A

SOIL CONSERVATION SERVICE TABLES

Table A-1

S.C.S. TABLE 1. STEP DESCRIPTION OF SOILS OF INDIA AND THEIR ESTIMATED PHYSICAL AND CHEMICAL PROPERTIES  
(The absence of figures or ratings indicates no information available or no estimate made at this time.)

S.C.S. TABLE 1. UNIFORM DESCRIPTION OF SOILS OF ILLINOIS AND THEIR ESTIMATED PHYSICAL AND CHEMICAL PROPERTIES (The absence of figures or ratings indicates no information available or no estimate made at this time.)																		November 1964 USDA, Soil Conservation Service	
Symbol on map (1)	Soil Name (2)	Description of Soil (3)	Depth from surface (4)  Feet	Classification				Percentage passing sieve				Thermal- conductivity (12)  Inches per foot of soil	Reaction (13)  pH value	Plant Resistance (14)	Drain- age Resistance (15)	Seasonal water table (16)	Depth to water (17)  Feet		
				USDA Texture (5)	Unified (6)	AASHTO (7)	No. 10 (2.0mm) (8)	No. 20 (0.85mm) (9)	No. 40 (0.425mm) (10)	No. 60 (0.25mm) (11)									
3445	Aboligum silty clay loam	Depressional and level soils on outwash plains and terraces; very poorly drained; developed in silty and loamy outwash materials; underlain by stratified gravel and sand; high organic surface and some areas of mucky phase. Flooded with high water table.	0-20 Silty clay loam	CL	A-6		100	100	95-100	85-95	0.2-0.8	.20	6.0-7.0	Moderate	Moderate	Flooded 0-3	15d		
802	Abolite silt loam	Laustrum plain deposits on stratified silty clay loam and clay loam; somewhat poorly drained. The subsoil contains thin strata of sand and silt.	0-10 Silt loam	ML	A-4		100	100	95-100	85-95	0.8-2.5	.20	6.1-6.5	Moderate	Low	1-3	15d		
7635	Ada loamy fine sand	Sandy low dunes on outwash plains, moraines and till plains. Successively drained soils having loamy sand surface layers over alternating layers of sand and loamy sand or sandy loam; finer textured layers usually less than 6 inches thick. Surface layers have high organic matter.	0-24 Loamy fine sand	SM	A-2		95-100	90-100	80-100	15-25	5.0-10.0	.08	5.5-6.5	Low	Low	Deep	15d		
82	Adler silt loam	Alluvial bottomland soil; moderately well drained; 2 to 4 feet of silt loam, underlain by stratified layers of silt loam and loam, subject to occasional or frequent flooding.	0-36 Silt loam	ML or CL	A-4		100	100	95-100	85-95	0.8-2.5	.20	6.1-6.5	Moderate	Low to moderate	3-5	15d		
7220	Adrian muck	Organic texture in level or depressional areas on lowlands, with organic material in 12 to 42 inches deep over loamy fine sand or sand; water table at or near the surface unless drained.	0-30 Muck	PS	—		—	—	—	—	2.5-5.0	.25	Variable	Low	Low	Flooded 0-3	15d		
556	Alford silt loam	Washlow loam deposits; well drained; loam deposits are 10 to 30 feet deep over residuum or Illinoian glacial till.	0-14 Silt loam	ML or CL	A-4		100	95-100	90-95	85-95	0.8-2.5	.20	5.6-6.5	Moderate	Low to moderate	Deep	20-50d Minor areas p. than 10		
107	Aligera silt loam	Alluvial soils; low distinct deposits of stream-bed materials, younger surface material is lighter in color, the older underlying material is generally dark colored; poorly drained; seasonal flooding.	0-26 Silt loam	ML or CL	A-4		100	100	95-100	85-95	0.8-2.5	.20	6.1-6.5	Moderate	Low	0-2	15d		

**Table A-2**  
**INTERPRETATION OF THE SOILS IN INDIANA**  
**FOR**  
**RURAL AND URBAN DEVELOPMENT**

June 1965

Soil Name (1)	Farm Crops (2)	Woodland (3)	Degree of Limitation and Soil Features Affecting Use			Light Industry & Commercial Buildings (6)	Highways & Roads (7)
			With Public Sewer (4)	Without Public Sewer (5)	Residential Development		
Abington silty clay loam 0-2%	Slight-wetness hazard for long periods	Moderate-species of economic value do not grow or grow slowly	Severe-depressional, high water table; often ponded; slow to very slowly permeable; subject to wet basements	Severe-depressional, high water table; often ponded; slow to very slowly permeable; subject to wet basements; restrict sanitary systems	Severe-depressional, high water table; often ponded; fair bearing strength; subject to frost heave	Severe-depressional, high water table; often ponded; fair bearing capacity; subject to frost heave; moderate to high shrink swell	
Abington silt loam 0-2%			Moderate-seasonal high water table; fair bearing strength; subject to frost heave	Severe-seasonal water table; moderately slow permeability; restrict sanitary systems	Moderate-seasonal high water table; fair bearing strength; subject to frost heave; moderate shrink swell	Moderate-seasonal high water table; fair bearing capacity; soil finer than optimum	
Aboite silt loam 2-6%, slightly eroded			Moderate-seasonal high water table; fair bearing strength; subject to frost heave	Severe-seasonal water table; moderately slow permeability; restrict sanitary systems	Moderate-seasonal high water table; fair bearing strength; subject to frost heave; moderate shrink swell	Moderate-seasonal high water table; fair bearing capacity; soil finer than optimum	
Ade loamy fine sand 0-6%	Moderate-sandy, droughty and wind erosion hazard	Moderate to Severe-sandy and droughty; suitable for pine (Christmas trees)	Severe-no problem for public sewer but droughty for lawns and shrubs	Severe-septic tanks function well; possible contamination of private water systems; droughty for lawns and shrubs	Slight-good bearing strength; droughty for lawns and shrubs	Moderate-severe erosion hazard in cuts and fills; difficult to maintain vegetation	
Ade loamy fine sand 6-12%	Moderate to Severe-sandy, droughty and wind erosion hazard	Moderate to Severe-sandy and droughty; suitable for pine (Christmas trees)	Severe-no problem for public sewer but droughty for lawns and shrubs	Severe-septic tanks function well; possible contamination of private water systems; droughty for lawns and shrubs	Slight-good bearing strength; droughty for lawns and shrubs	Moderate-severe erosion hazard in cuts and fills; difficult to maintain vegetation	



Table A-3

S.C.S. TABLE 3. INTERRELATIONS OF ENGINEERING PROPERTIES OF SOILS - MODIFIED

NATIONAL BUREAU OF STANDARDS

SD-16-102  
April 1965

Soil Type Name (1)	Sustainability as Source of (2)		Sustainability for (3)		Soil Factors Affecting Engineering Properties (4)		Engineering Potential for Concrete (5)
	Topsoil (a)	Subsoil and Lower (b)	Bedrock (c)	Foundations for Buildings (d)	Highway Location (e)	Depth for Increased Fields (f)	
Subaqueous silty clay loam	Surface: fair; Subsoil: fair to poor; clayey; near water table.	Hard, good; Special: fair to good below 5 feet.	Substratum: good; good bearing capacity; low volume change; low shrink-swell.	Substratum: fair; seasonal high water table; low volume change; good bearing capacity.	Seasonal high water table; fair to poor bearing capacity above 3 feet; subject to frost heave.	Severe (limitations; seasonal high water table; moderately impenetrable; low permeability).	Metal: high Concrete: low
Subsilty silt loam	Surface: good; Subsoil: fair; permeable high water table.	Not suitable	Subsoil and substratum: poor to fair; moderate to high volume change; poor to very poor bearing capacity; periodic high water table; difficult to work and compact when wet.	Seasonal high water table; fair to poor bearing capacity; moderate to high volume change; moderate compressibility and shear strength.	Seasonal high water table; hinders construction in wet areas; subject to frost heave; fair bearing capacity.	Severe (limitations; seasonal high water table; moderately impenetrable; low permeability; lighter).	Metal: high Concrete: low
Low sandy fine sand	Surface and subsoil poor; low available moisture capacity.	Fair; highly variable stratified subsoil	Substratum: fair to good; low volume change; good to fair bearing capacity; low moderate compressibility; loads exceed when compacted; shrink- swell potential; low frost potential.	Good to fair; moderate shear strength; low compressibility; low shrink-swell; readily penetrable.	Good and fills often needed; loads may interfere with faster building.	Slight (limitations; rapid penetration; poor material; need of subdrainage; need of water supply; shrink-swell problem; low frost potential; low permeability).	Metal: low Concrete: low
Adrian mud (12 to 18 inches deep over sand)	Non-erosive; indicates rapidly.	Fair; unconsolidated; seams are variable; high water table.	Fair; poor - unstable; should be avoided; high water table; substratum, sand and gravel and fines.	Not suitable; unstable; depressional; high water table.	Not suited; organic material; shrink-swell; depressional; high water table.	Not suited; depressional; high water table.	Metal: very high in sand; moderate in mud; Concrete: low; below 12 to 18 inches high.
Alford silt loam	Surface: good; deep; erosive; Subsoil: fair; erod- ible on slope.	Not suitable	Subsoil and substratum: poor; high volume change; low stability; poor bearing capacity; erodible.	Good to fair; moderate shear strength and compressibility; not subject to frost heave; fair to poor bearing capacity.	Good and fills often needed; shrink-swell; poor bearing capacity; erodible on slopes.	Slight (limitations; moderate stability; permeable material).	Metal: low Concrete: low
Algiers silt loam	Surface: good; Subsoil: good; subject to stream flooding.	Not suitable	Subsoil and substratum: poor; moderate to high volume change; poor bearing capacity; difficult to compact when wet; subject to frost heave.	Fair; subject to flooding with seasonal high water table; not subject to frost heave; fair to poor bearing capacity.	Subject to flooding; high water table; subject to frost heave.	Severe (limitations; subject to flooding; high water table).	Metal: high Concrete: low
Alma silt loam	Surface: good; Subsoil: fair; somewhat clayey.	Subsoil: not suited; Substratum: good; sand, no gravel, shale fragments.	Subsoil: fair to good; moderate to high volume change; fair bearing capacity; substratum: good; low volume change; good bearing capacity.	Good; moderate to high shear strength; low compressibility; rapid permeability; low shrink- swell.	Good and fills often needed; moderate volume change; subject to frost heave.	Slight (limitations; moderate stability; permeable material).	Metal: low to moderate; Concrete: low
Almesterville silt loam	Surface: good; Subsoil: fair; lower subsoil clayey.	Not suitable	Subsoil: fair; moderate; poor; moderate to high volume change; fair to poor bearing capacity; fragments in subsoil.	Good to fair; moderate shear strength and compressibility; moderate, poor compressibility; ability; limitations 3-5 feet; fragments in subsoil.	Good and fills often needed; low shrink-swell; fair to poor bearing capacity; erodible on slopes.	Moderate (limitations; moderate stability; permeable; low shrink-swell; fragments in subsoil).	Metal: moderate Concrete: low
Altamont silt loam	Surface: good; deep, erosive; Subsoil: fair; SEVERE ON SLOPE	Not suitable	Subsoil and substratum: poor; high volume change; low permeability; poor bearing capacity.	Good to fair; moderate shear strength and compressibility; moderate; low to moderate ability; limitations 3-5 feet; fragments in subsoil.	Good and fills often needed; variable when wet; poor bearing capacity; erodible on embankments.	Slight (limitations; moderate stability; permeable material).	Metal: low Concrete: low
Altman silt clay loam	Surface: fair; Subsoil: good	Not suitable	Subsoil and substratum: poor; high volume change; difficult to compact when wet; subject to flooding; high water table.	Fair; moderate shear strength and compressibility; permeable; subject to seasonal flooding; low to moderate shrink-swell.	Subject to erosion and high water table; subject to frost heave.	Severe (limitations; moderate stability; permeable material).	Metal: moderate Concrete: low

Table A-4

S.C.S. TABLE 4. INTERPRETATION OF REQUIREMENTS FOR GRADES 30:100 IN INDIANA FOR  
CONCRETE

1954-55  
APRIL 1955

Soil Type Name (1)	Seepage Area (2)	Stress, Load or Underpinning (3)	Agricultural Drainage (4)	Terraces and Diversions (5)	Grass Waterways (6)
Alluvial clay loam	Seasonal, high water table; surface and subsurface; fair to good seepage rate; subsurface rapid seepage rate; suitable for all ponds.	Seasonal, high water table; surface and subsurface; fair to good stability and subsurface; fair to good seepage rate; subsurface rapid seepage rate; suitable for all ponds.	Seasonal, high water table; fair to moderate seepage rate; subsurface rapid seepage rate; suitable for all ponds.	Not needed; level and depression; diversions reduce runoff from adjacent areas.	Not needed; level and depression; diversions reduce runoff from adjacent areas.
Alluvial silt loam	Medium to slow seepage rate; seasonal, high water table.	Fair to good stability and subsurface; fair to good seepage rate.	Drainage is only needed; moderately slow permeability; high water table; depression well; good surface drainage.	Usually not needed; gentle slopes with little runoff.	No limitation upon the maximum high water table.
Alluvial fine sand	Sandy material; fair to good seepage rate; seasonal, high water table.	Slight to very slight compression; fair to good stability; fair to good seepage rate.	Not needed.	Not needed; porous sand; little runoff; difficult to vegetate.	Not needed; porous sand; little runoff; difficult to vegetate.
Alluvial mud	Poor; pervious; high water table; suitable for all ponds.	Poor; pervious; good to material; low stability; subsurface has high stability; subject to piping.	Organic material; subsurface; high water table; subsurface and/or surface drainage needed; covered; less than 1/2" of water, not subject to erosion.	Not needed; depression; organic; diversions reduce runoff from adjacent areas.	Not needed; high water table; depression.
Alluvial silt loam	Well drained; medium to slow seepage.	Fair stability; good to poor compression; slow to good seepage; subject to piping.	Not needed; moderate permeability.	No limitation.	Usually sloping to slope; subject to runoff and erosion; not subject.
Alluvial silt loam	High water table; medium to slow seepage; subject to piping.	Fair stability; fair to poor compression; subject to piping.	Subject to overflow; high water table; adequate for all ponds.	Not needed; diversions reduce runoff from adjacent areas.	Not needed; level topography.
Alluvial silt loam	Well drained; medium to slow seepage; subject to piping.	Fair stability; fair to good compression; subject to piping.	Not needed.	No limitation except on slopes extending left.	No limitation; slopes subject to runoff and erosion.
Alluvial silt loam	Slow seepage; (see page 3-5).	Poor to fair stability; low to medium permeability; moderate seepage.	Not needed.	No limitation.	No limitation; slopes subject to runoff and erosion.
Alluvial silt loam	Well drained; medium to slow seepage.	Fair stability; good to poor compression; slow to good seepage; subject to piping.	Not needed; moderate permeability.	No limitation.	Usually sloping to slope; subject to runoff and erosion.
Alluvial silt loam	Subject to overflow; well drained.	Fair stability; fair to good compression; high water table; high seepage.	Not needed; moderate permeability.	Not needed; level topography.	Not needed due to level topography.
Alluvial silt loam	High water table; moderately slow permeability; suitable for all ponds.	Fair stability and fair compression; subject to piping.	High water table; moderately slow permeability; surface and subsurface drainage needed.	Not needed; level topography; diversions reduce runoff from adjacent areas.	Not needed; level topography; sloping areas subject to erosion.
Alluvial silt loam	High water table; medium to slow seepage rate; suitable for all ponds.	High water table; fair to good stability and compression; slow seepage rate.	High water table; moderately slow permeability; surface and subsurface drainage needed; depression.	Not needed; level and depression; diversions reduce runoff from adjacent areas.	Not needed; level and depression.
Alluvial silt loam	High water table; subject to overflow; slow seepage.	Fair stability; poor compression; high water table.	High water table; subject to overflow; subject to erosion; surface drainage by road side lines.	Not needed; level topography; well.	Not needed; level topography.
Alluvial silt loam	Good; (see material) fair compression and stability; subject to piping.	Good; (see material) fair compression and stability; subject to piping.	Drainage usually required; suitable for all ponds; (see material) fair to good stability; medium seepage rate; difficult to water when wet; seasonal, high water table.	Not needed; seasonal high water table.	Not needed.

APPENDIX B

DRIFT DEPTH AND TERRAIN ELEVATION INTERVAL  
VS. PERCENT AREA PHYSIOGRAPHIC REGION CURVES

# I. Northern Lake And Moraine Region

## A. Calumet Lacustrine Plain

PERCENT AREA PHYSIOGRAPHIC REGION

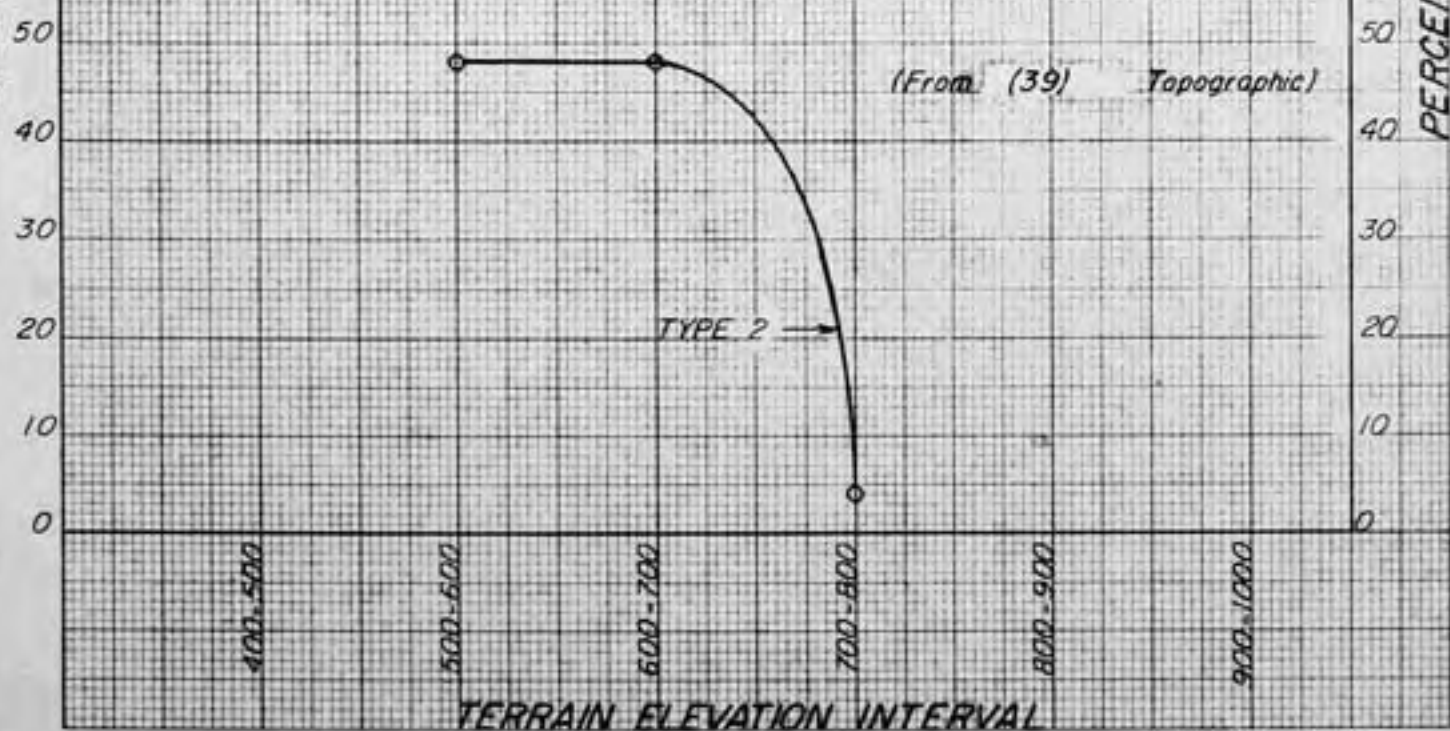
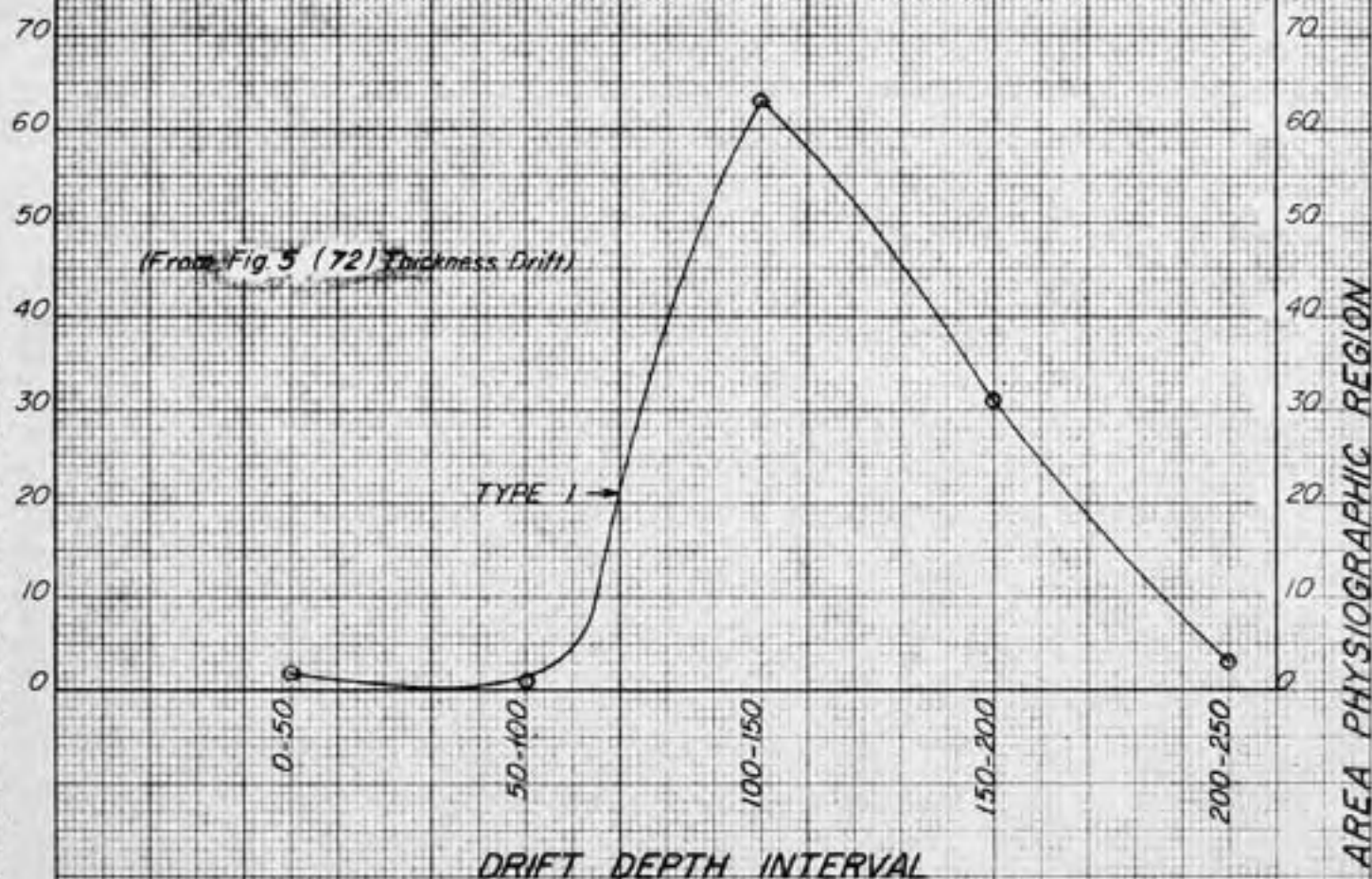


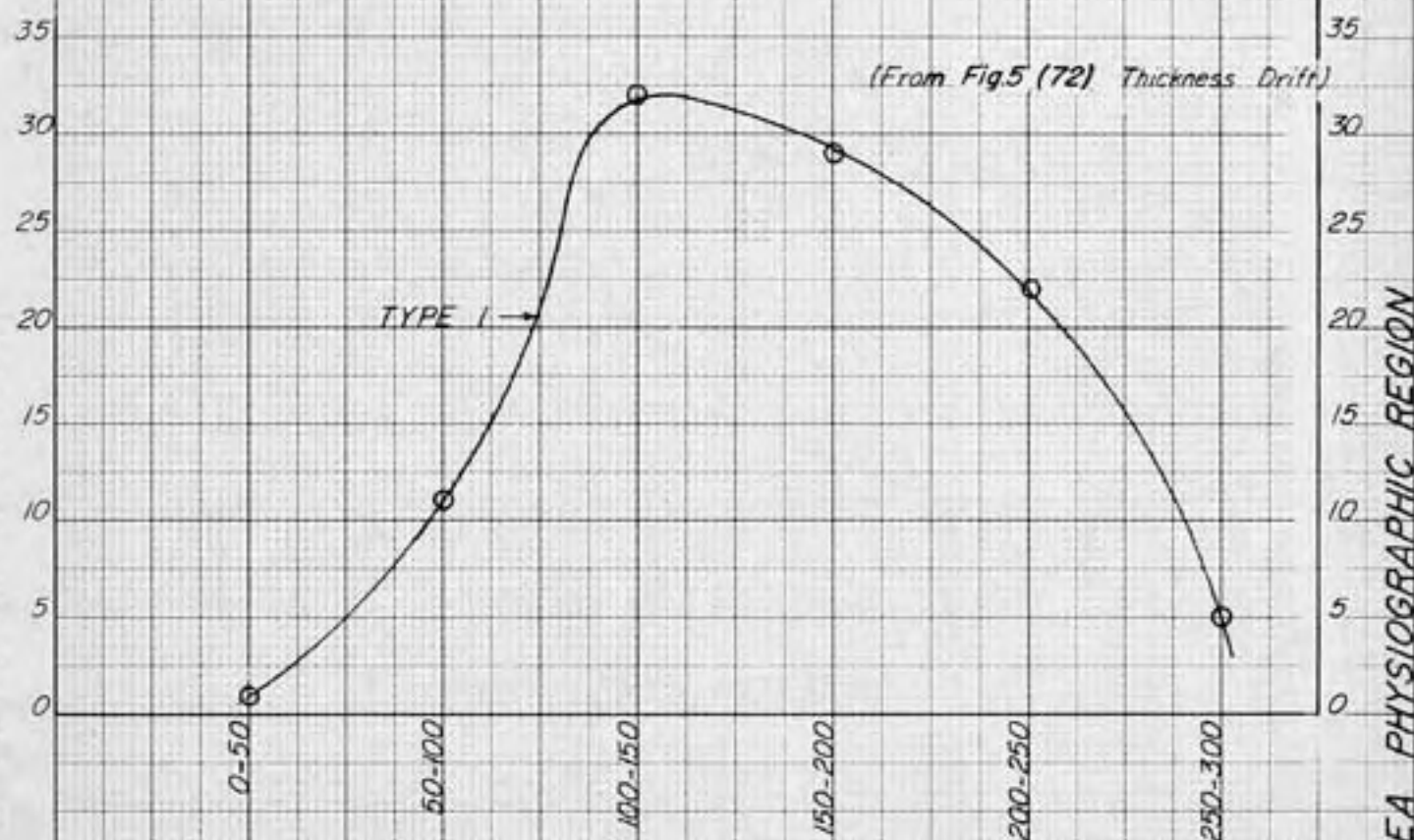
FIGURE B-1



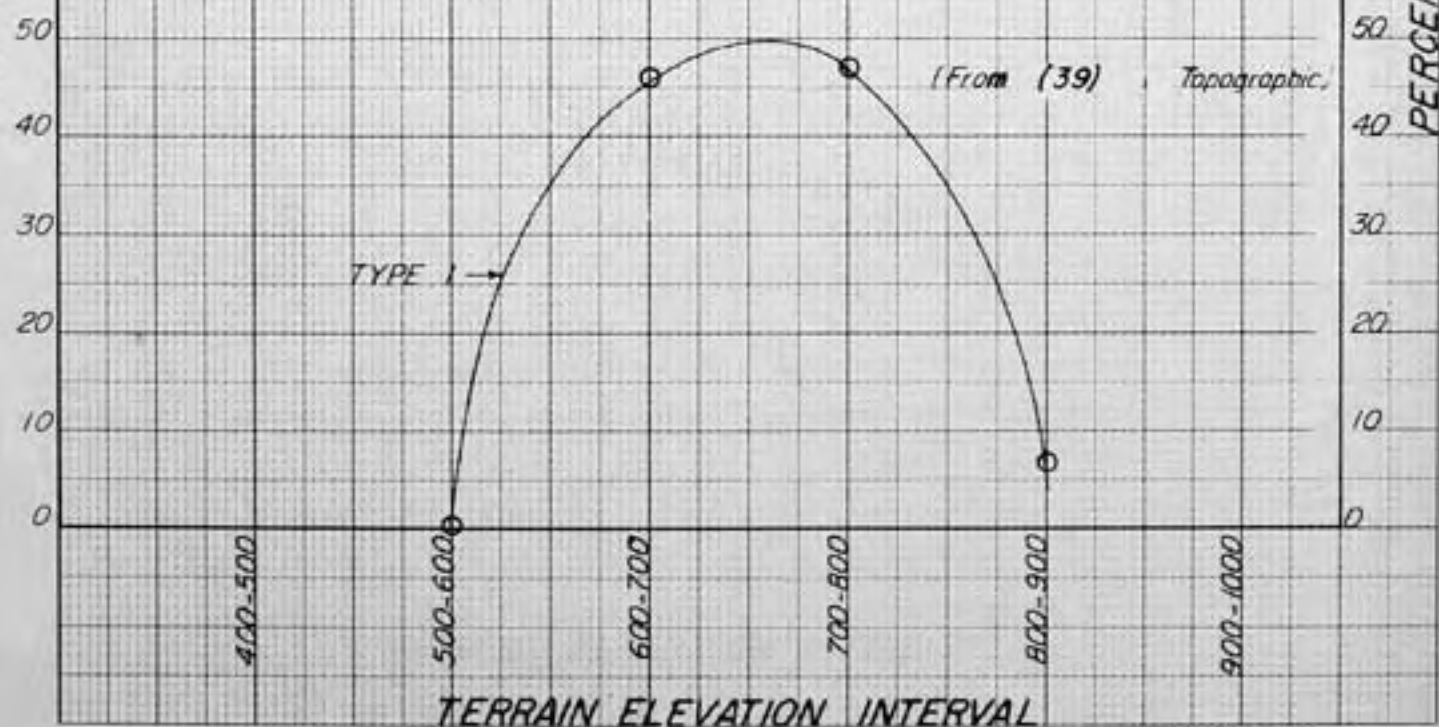
# I. Northern Lake And Moraine Region

## B. Valparaíso Morainal Area

PERCENT AREA PHYSIOGRAPHIC REGION



DRIFT DEPTH INTERVAL



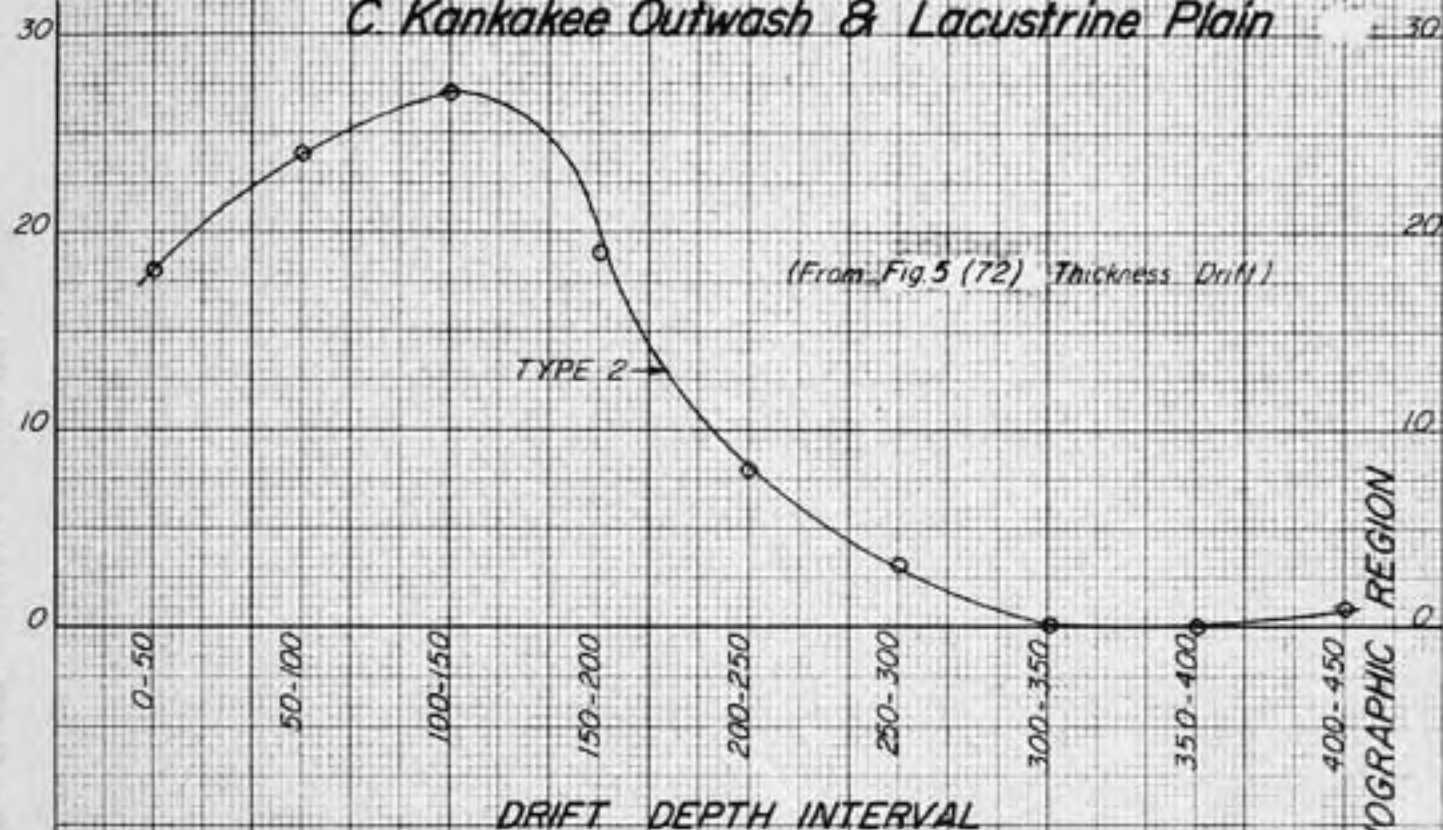
TERRAIN ELEVATION INTERVAL

FIGURE B-2

# I. Northern Lake And Moraine Region

## C. Kankakee Outwash & Lacustrine Plain

PERCENT AREA PHYSIOGRAPHIC REGION



PERCENT AREA PHYSIOGRAPHIC REGION

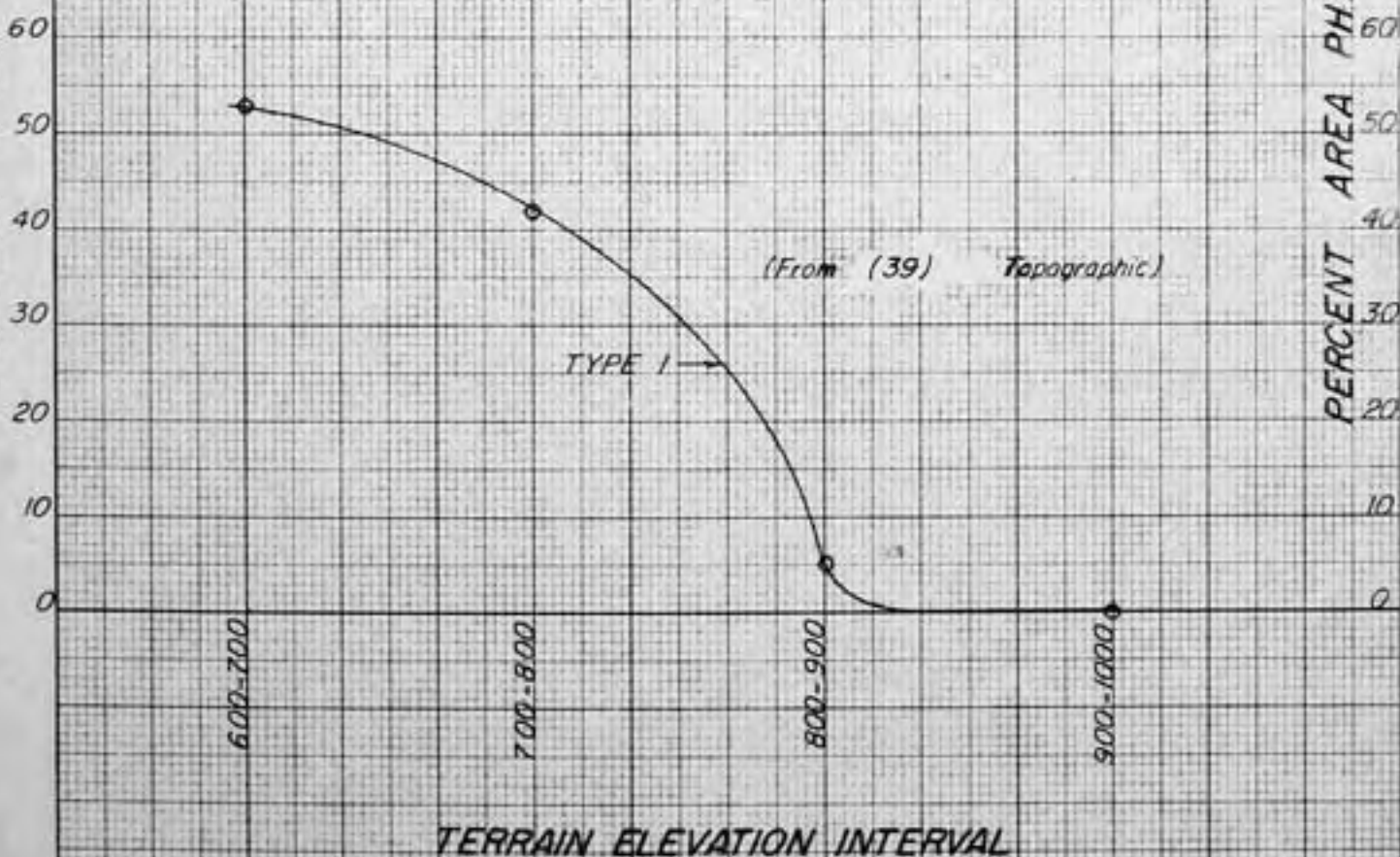


FIGURE B-3



# I Northern Lake And Moraine Region

## D Steuben Morainal Lake Area

PERCENT AREA PHYSIOGRAPHIC REGION

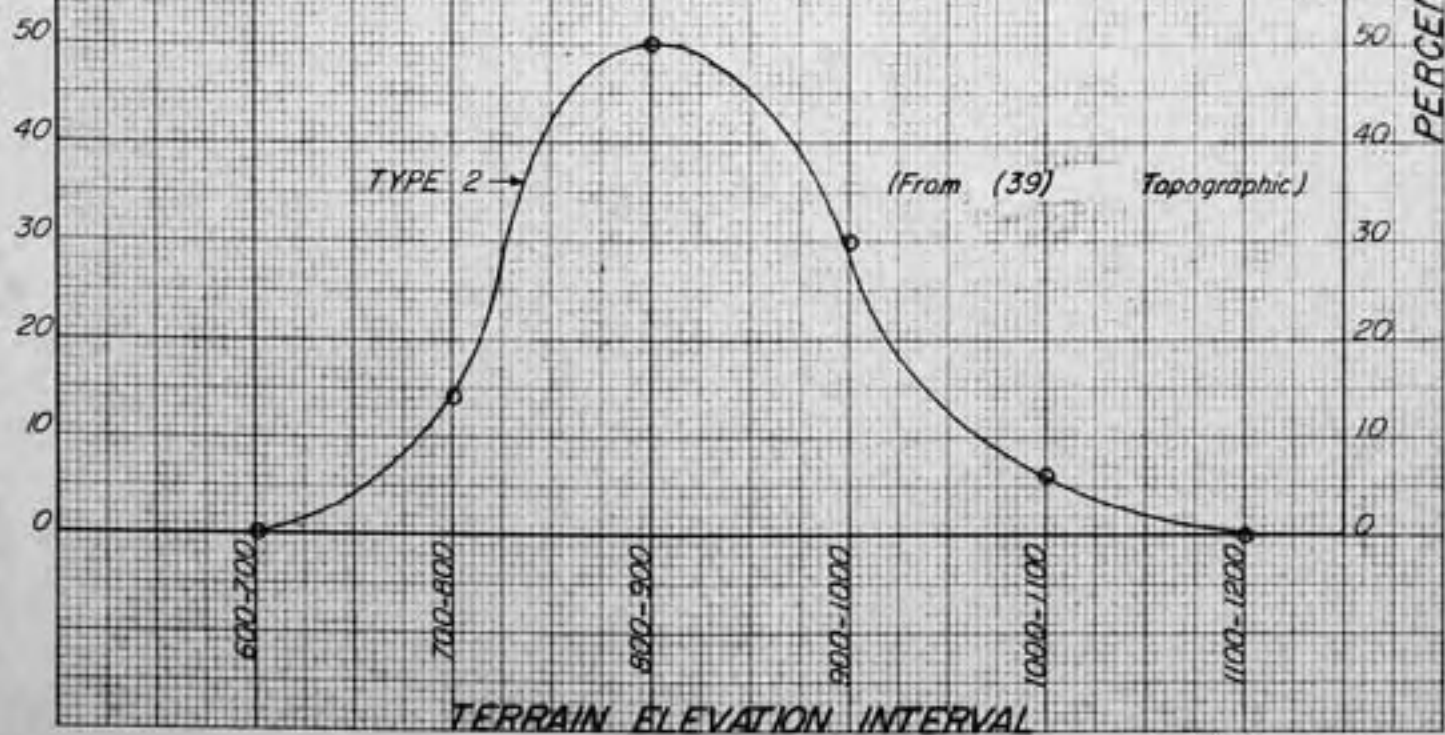
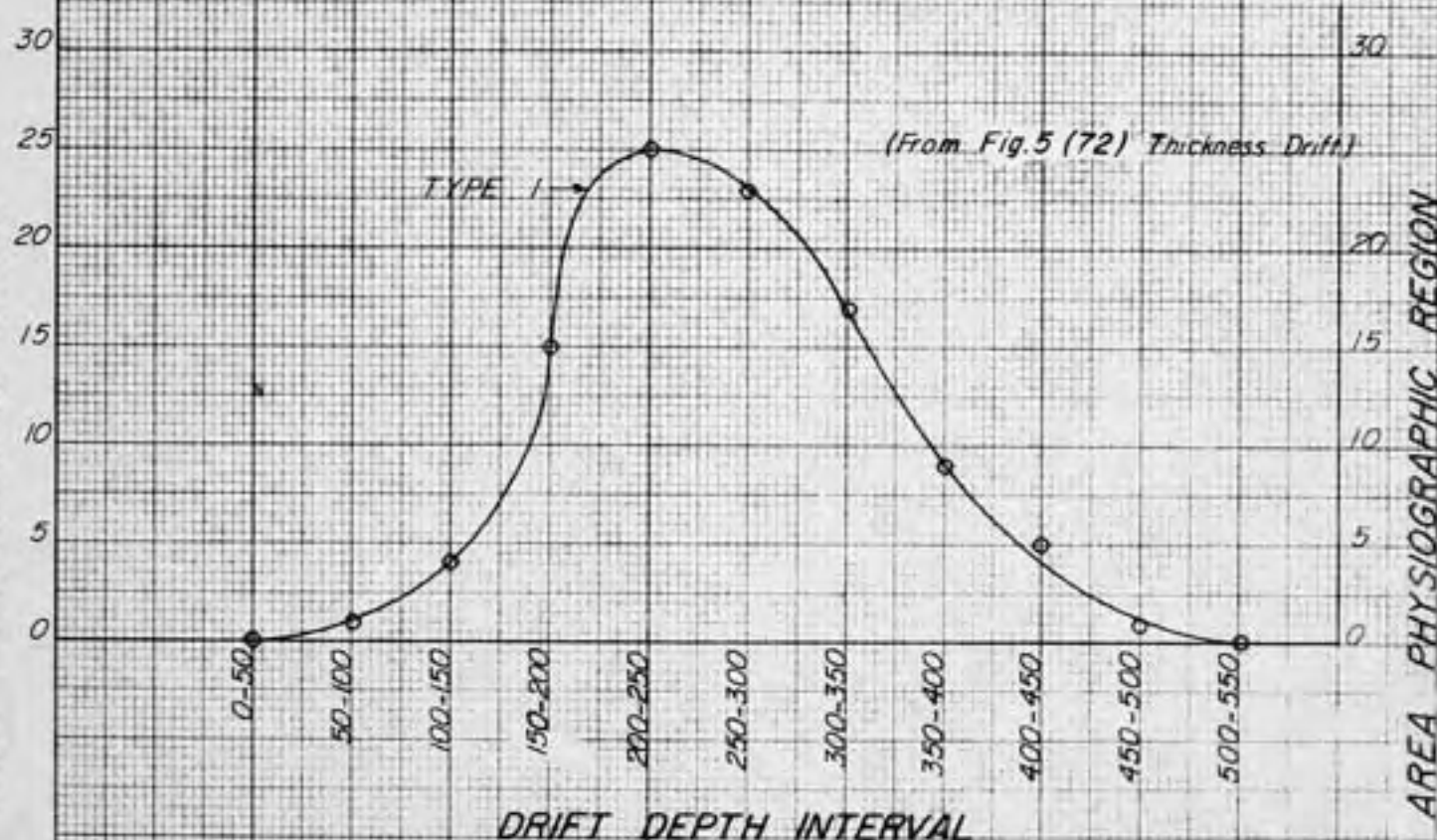


FIGURE B-4

# I. Northern Lake And Moraine Region

## E. Maumee Lacustrine Plain

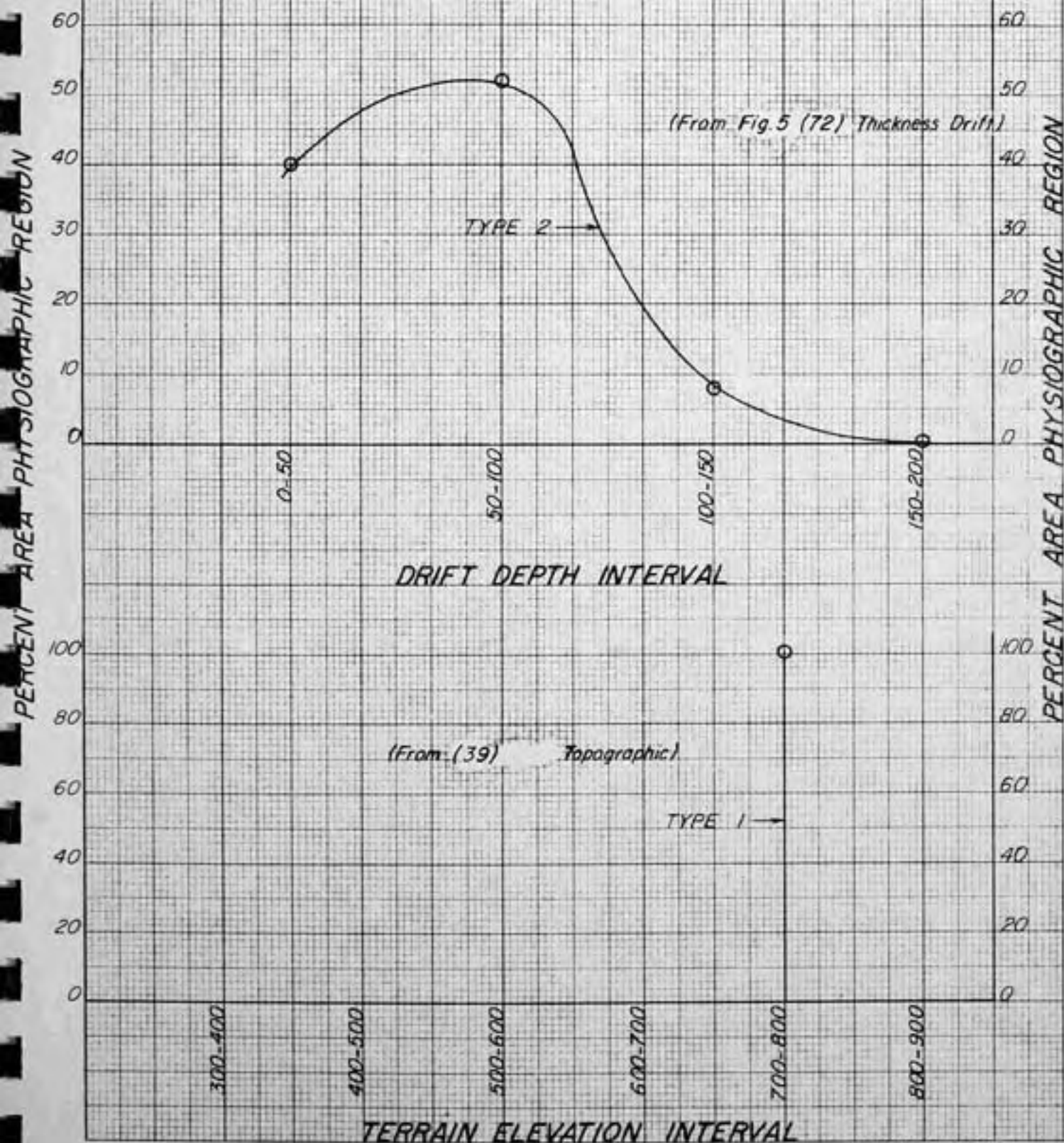


FIGURE B-5



## 2 Tipton Till Plain

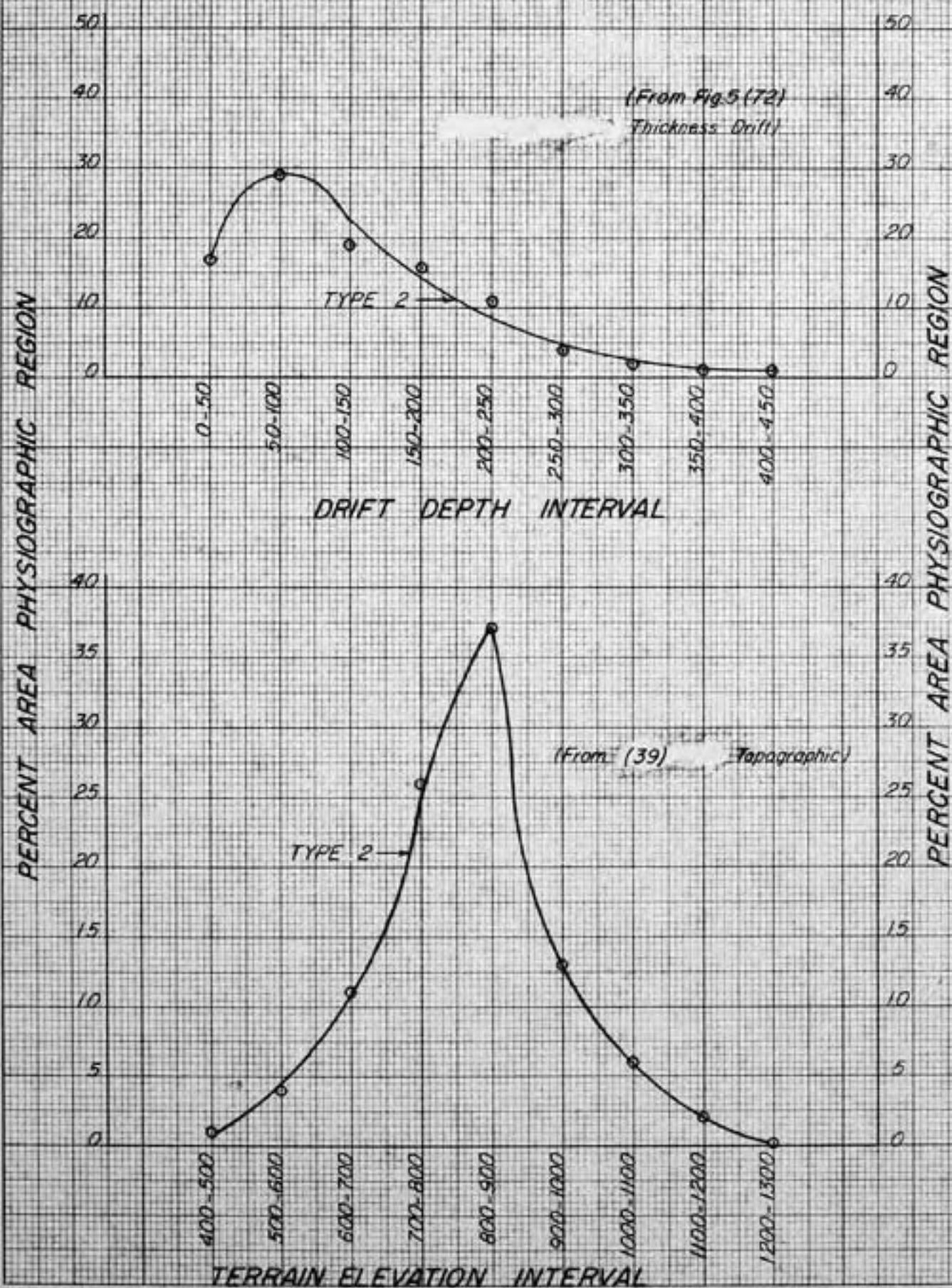


FIGURE B-6

### 3. Dearborn Upland

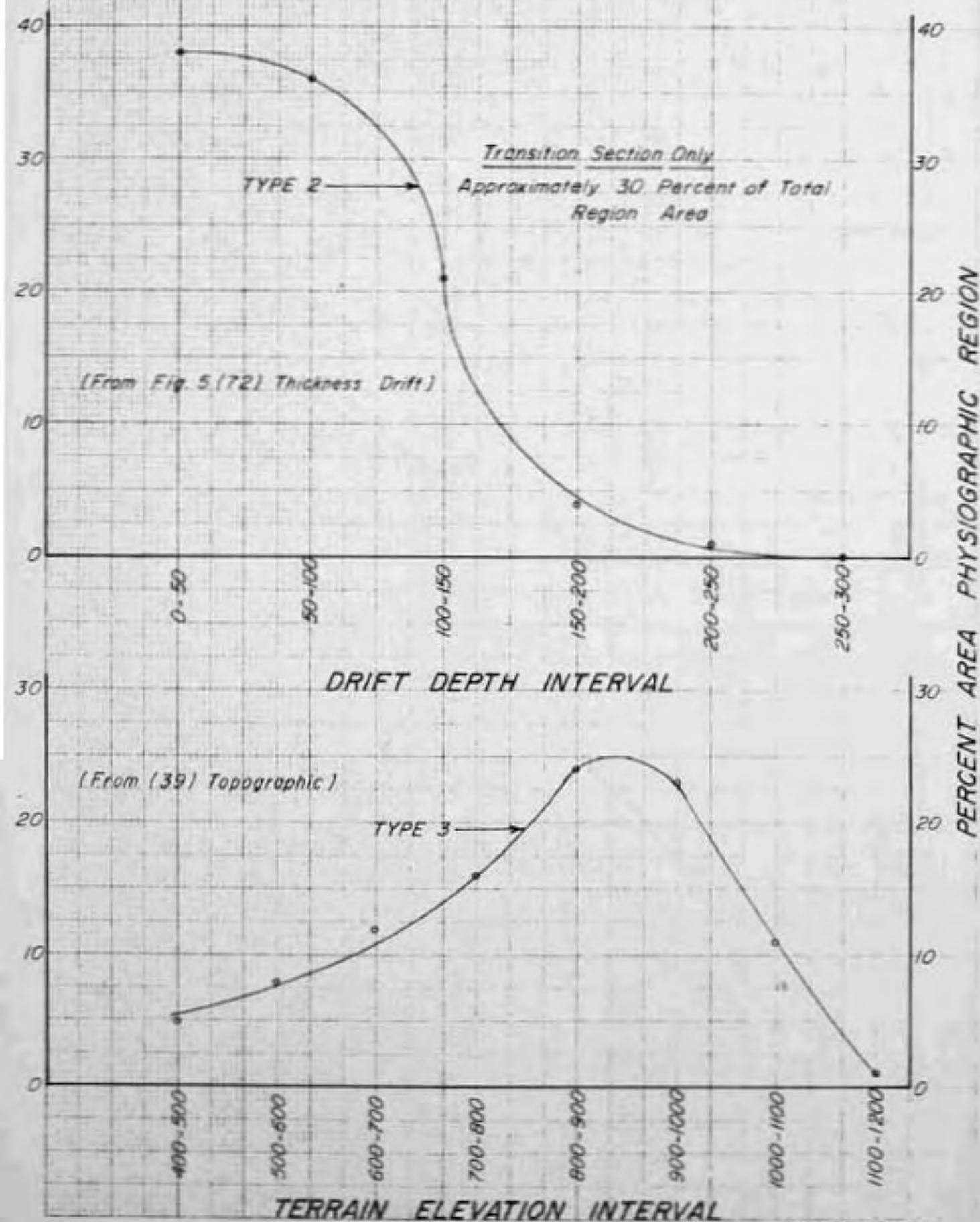


FIGURE B-7

# 4. Muscatatuck Regional Slope

PERCENT AREA PHYSIOGRAPHIC REGION

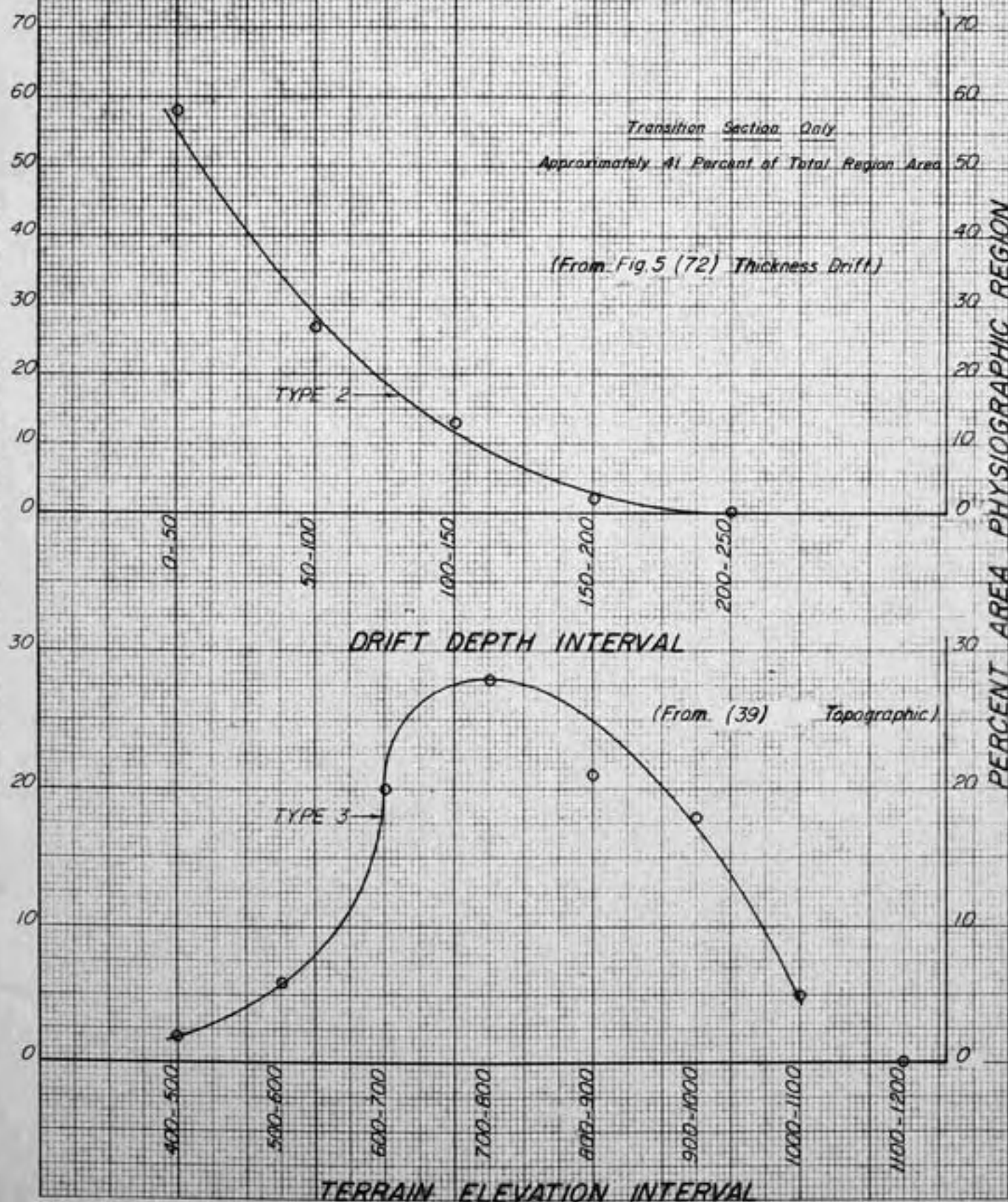


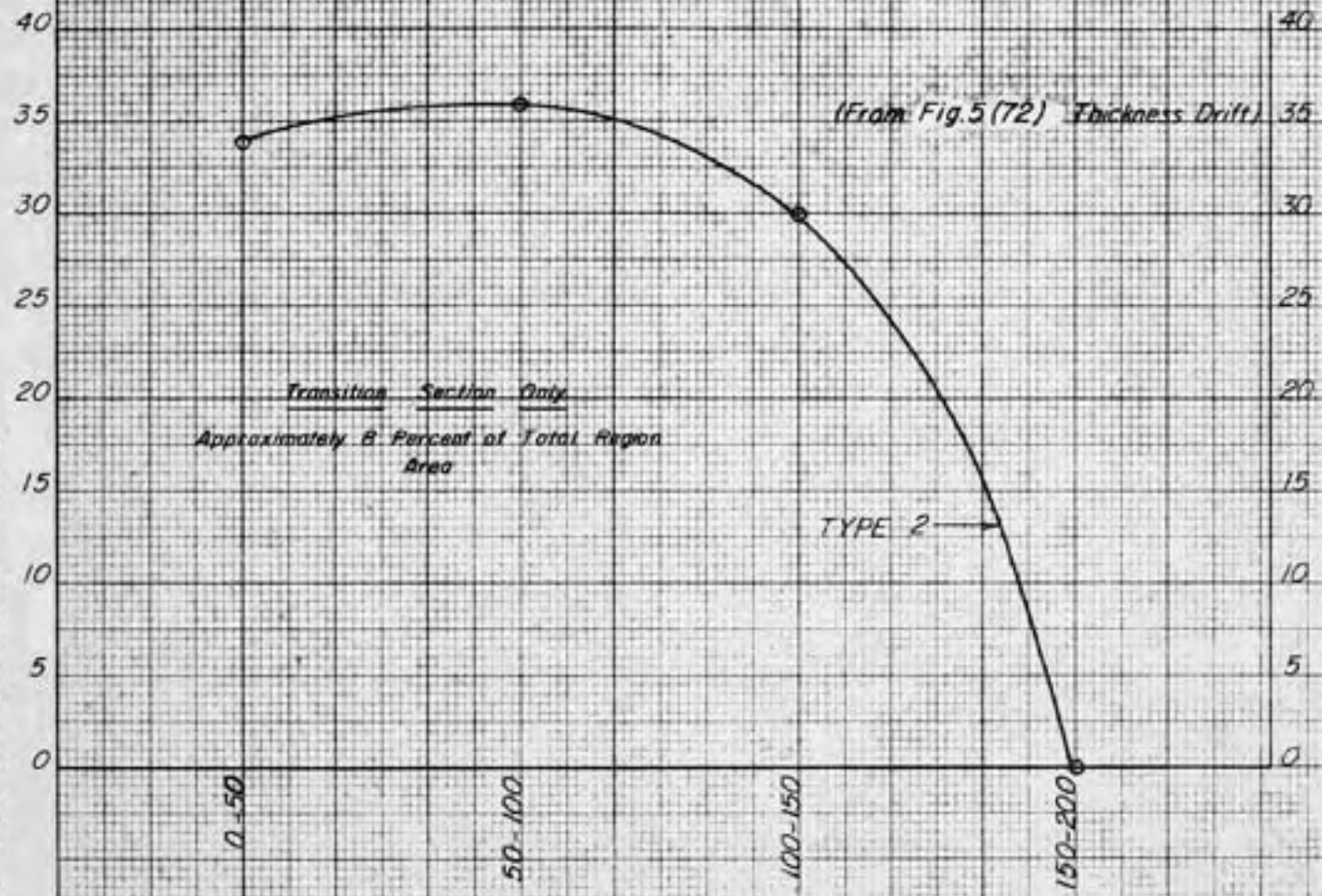
FIGURE B-8



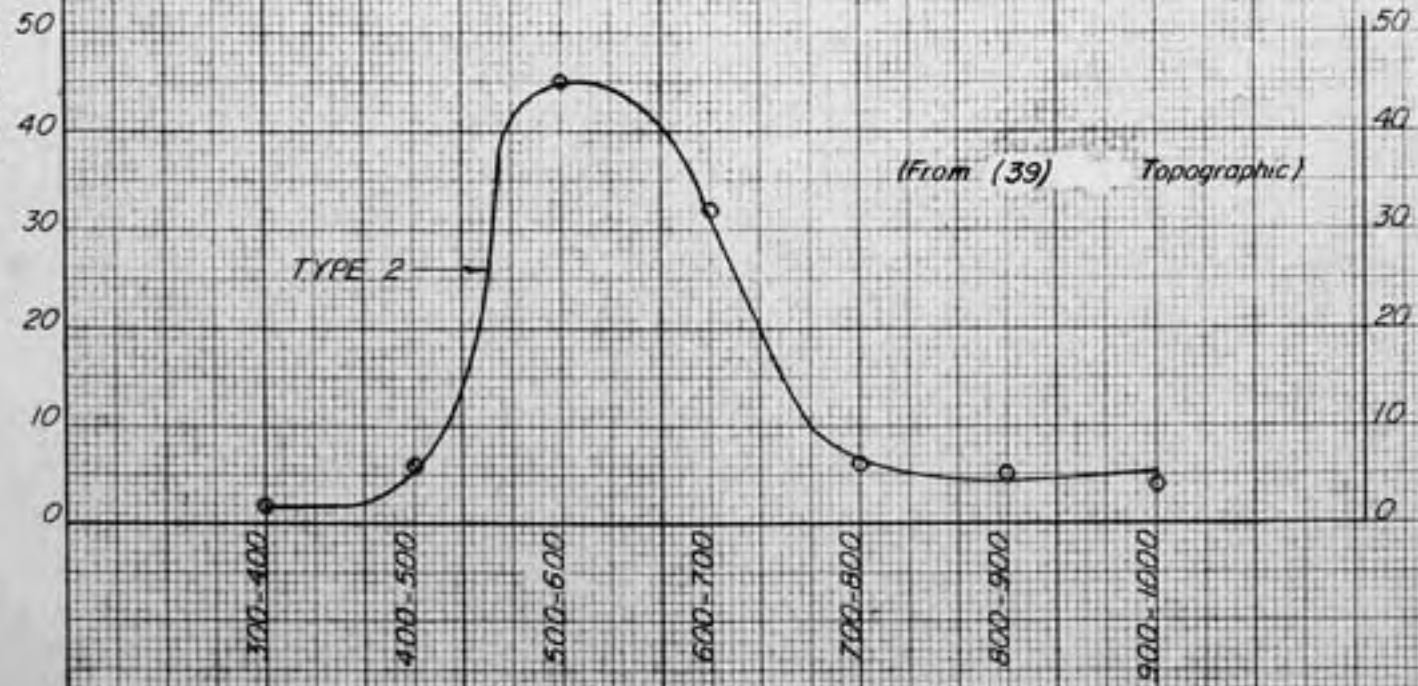
# 5. Scottsburg Lowland

PERCENT AREA PHYSIOGRAPHIC REGION

PERCENT AREA PHYSIOGRAPHIC REGION



DRIFT DEPTH INTERVAL



TERRAIN ELEVATION INTERVAL

FIGURE B-9



# 6. Norman Upland

PERCENT AREA PHYSIOGRAPHIC REGION

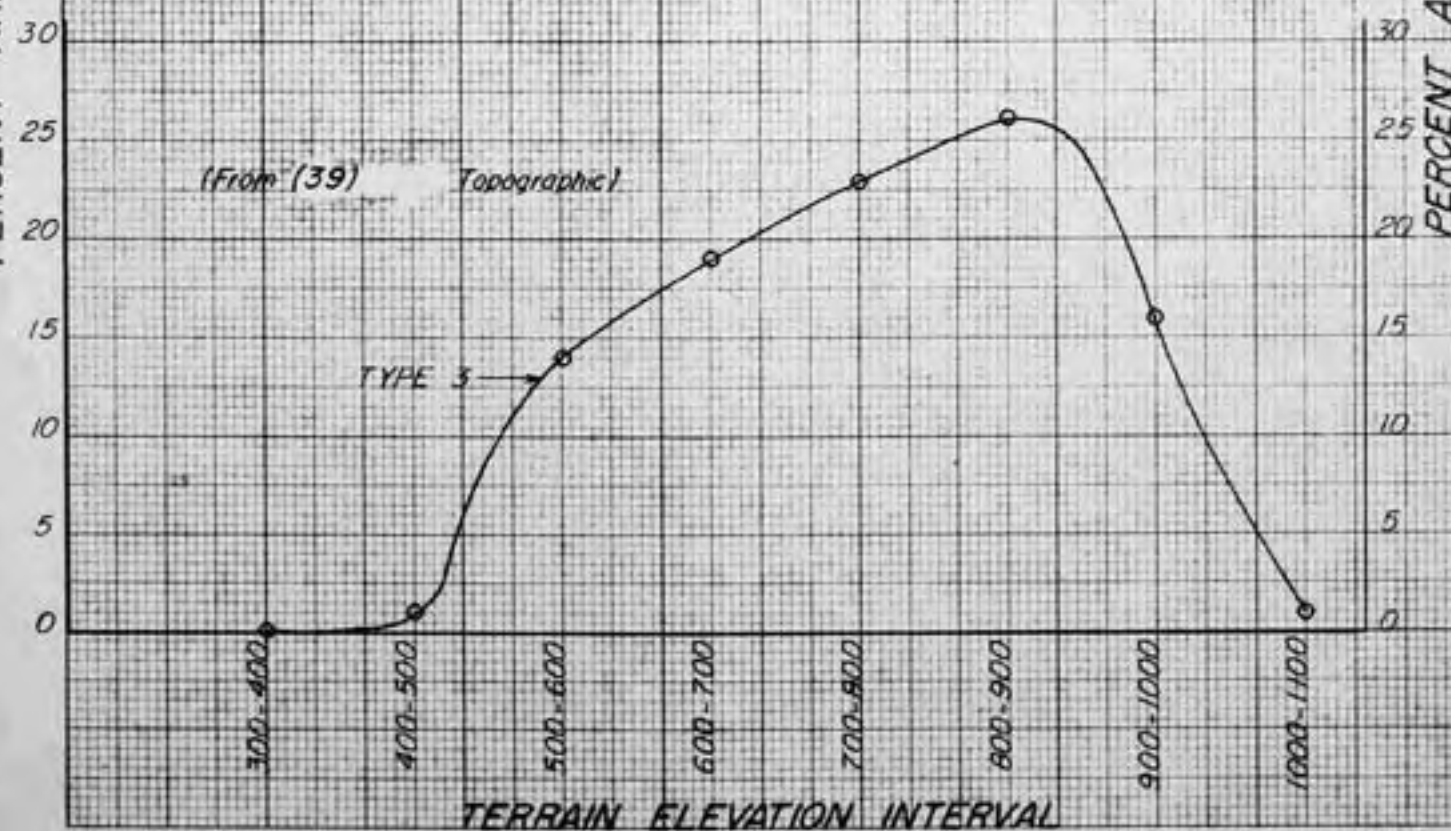
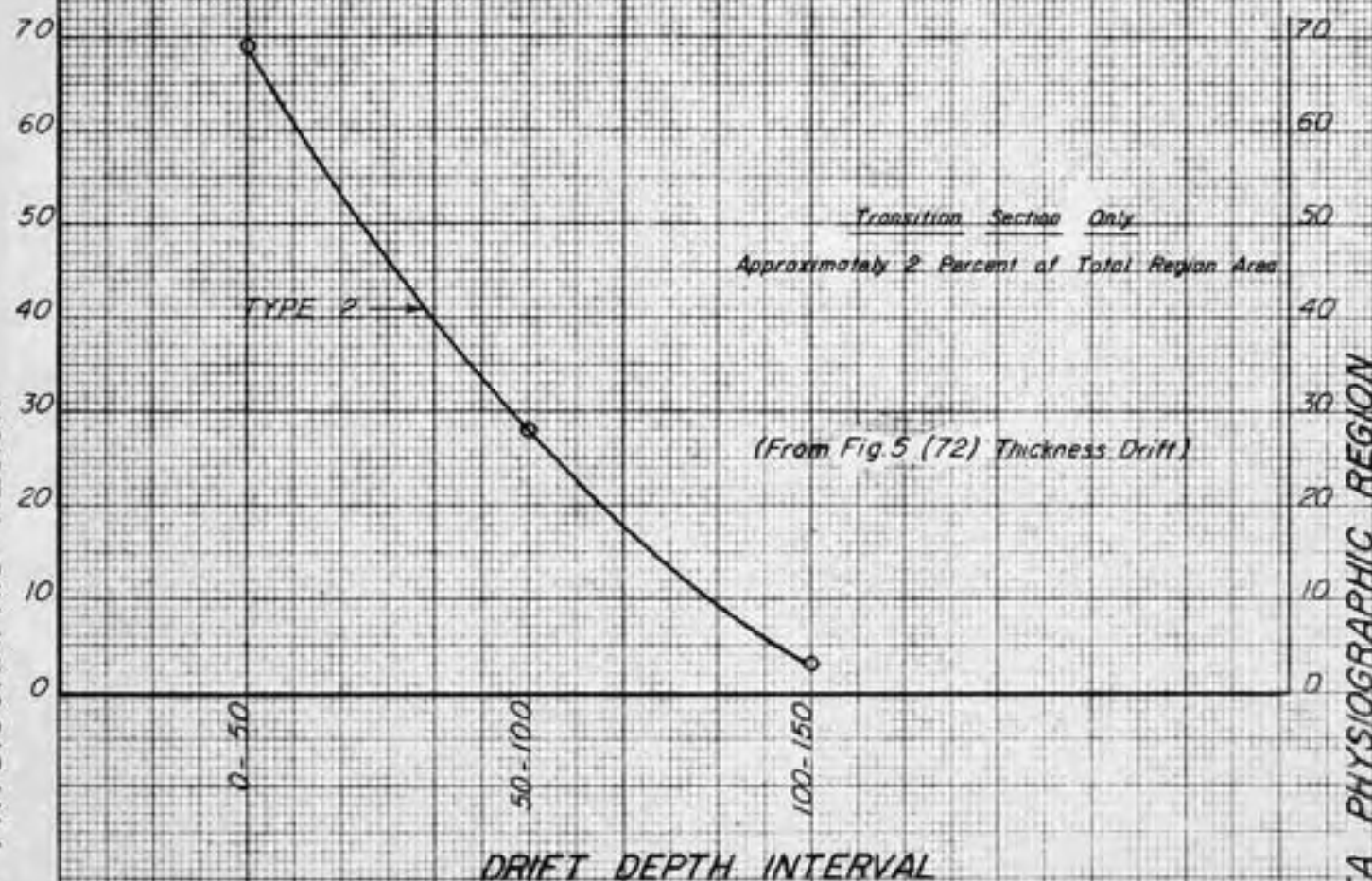


FIGURE B-10

## 7 Mitchell Plain

PERCENT AREA PHYSIOGRAPHIC REGION

50

40

30

20

10

0

(From (39) Topographic)

TYPE 2 →

300-400

400-500

500-600

600-700

700-800

800-900

900-1000

TERRAIN ELEVATION INTERVAL

50

40

30

20

10

0

PERCENT AREA PHYSIOGRAPHIC REGION

FIGURE B-11



# 8. Crawford Upland

PERCENT AREA PHYSIOGRAPHIC REGION

30

25

20

15

10

5

0

(From (39) Topographic)

TYPE 3

PERCENT AREA PHYSIOGRAPHIC REGION

30

25

20

15

10

5

0

300-400

400-500

500-600

600-700

700-800

800-900

900-1000

TERRAIN ELEVATION INTERVAL

FIGURE B-12

PERCENT AREA PHYSIOGRAPHIC REGION

## 9. Wabash Lowland

PERCENT AREA PHYSIOGRAPHIC REGION

TYPE 2 →

(From (39) Topographic)

PERCENT AREA PHYSIOGRAPHIC REGION

TERRAIN ELEVATION INTERVAL

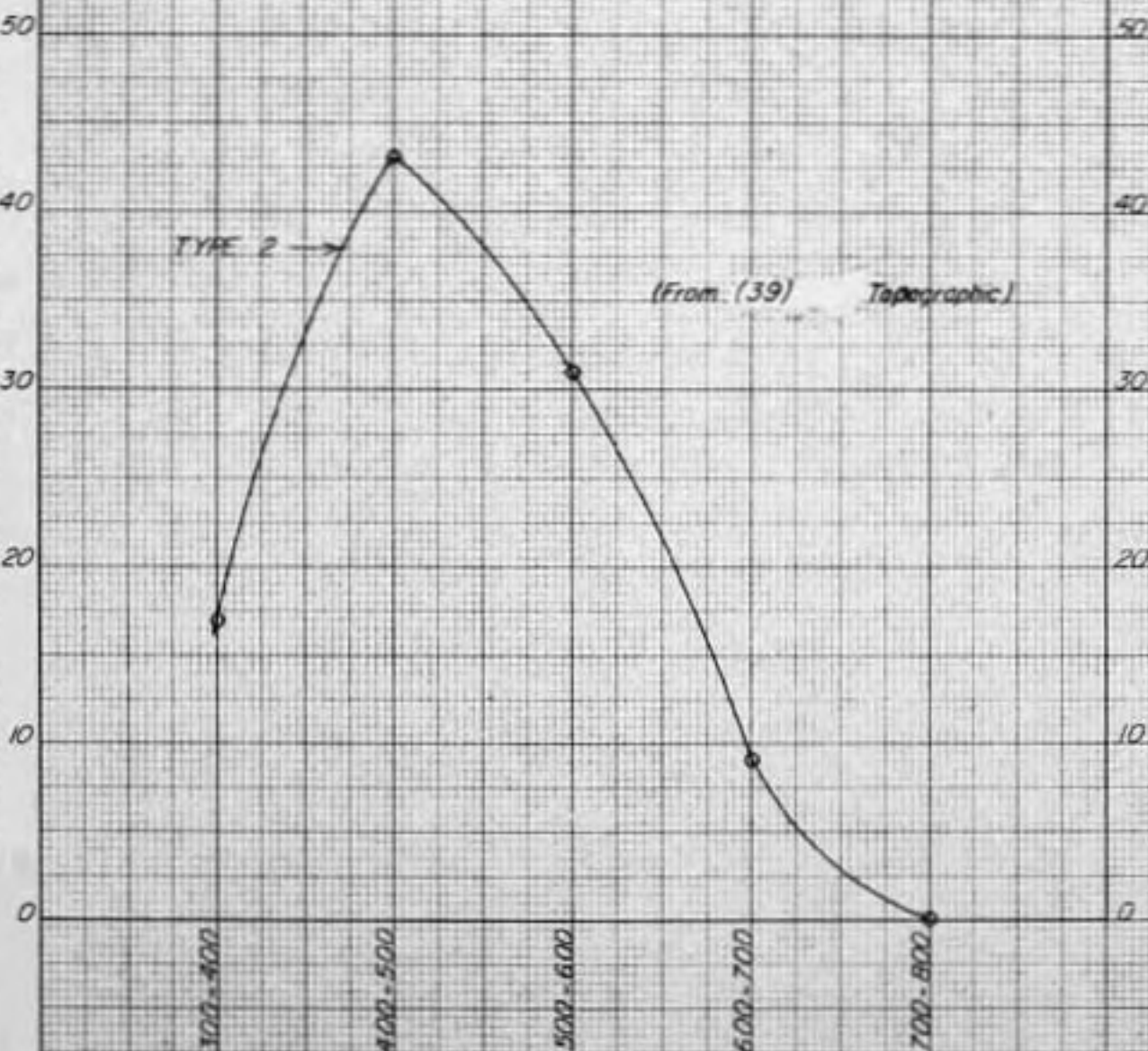


FIGURE B-13

APPENDIX C

SOIL TYPE AND SOIL TYPE NUMBER  
VS. PERCENT AREA PHYSIOGRAPHIC REGION GRAPHS



# I. Northern Lake And Moraine Region

## A. Calumet Lacustrine Plain

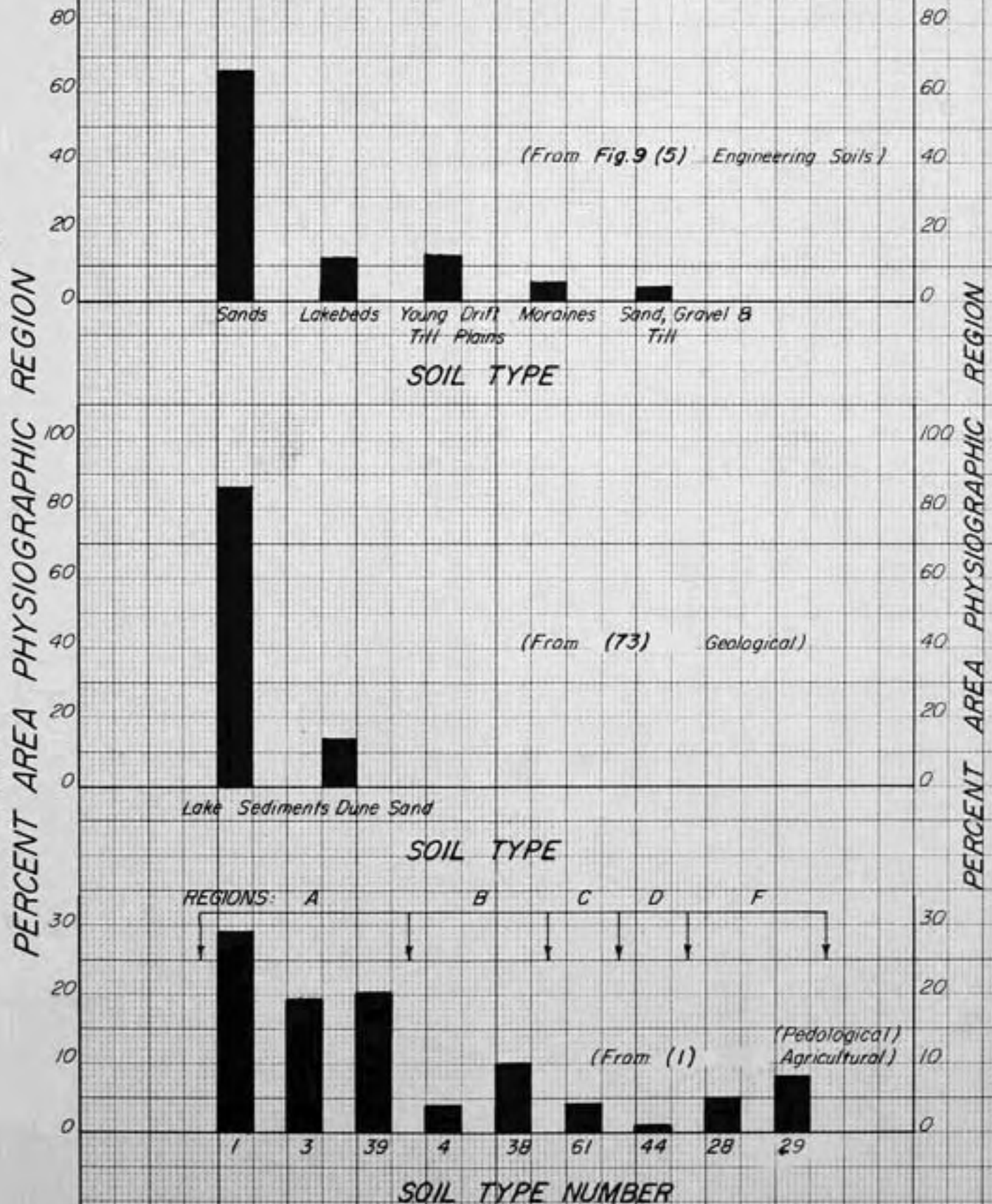


FIGURE C-1

# I. Northern Lake And Moraine Region

## B. Valparaiso Morainal Area

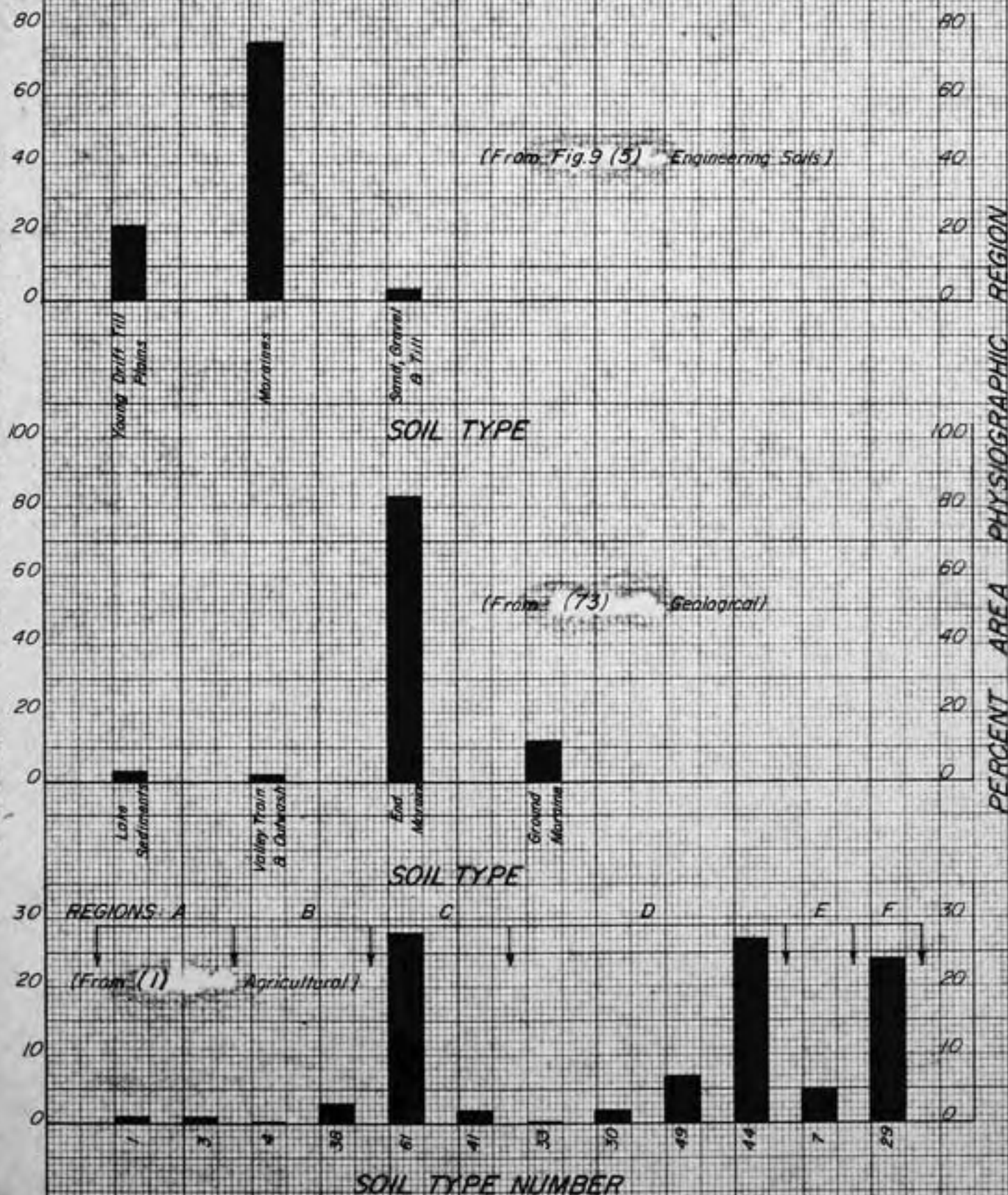


FIGURE C-2



# I. Northern Lake And Moraine Region

## C. Kankakee Outwash & Lacustrine Plain

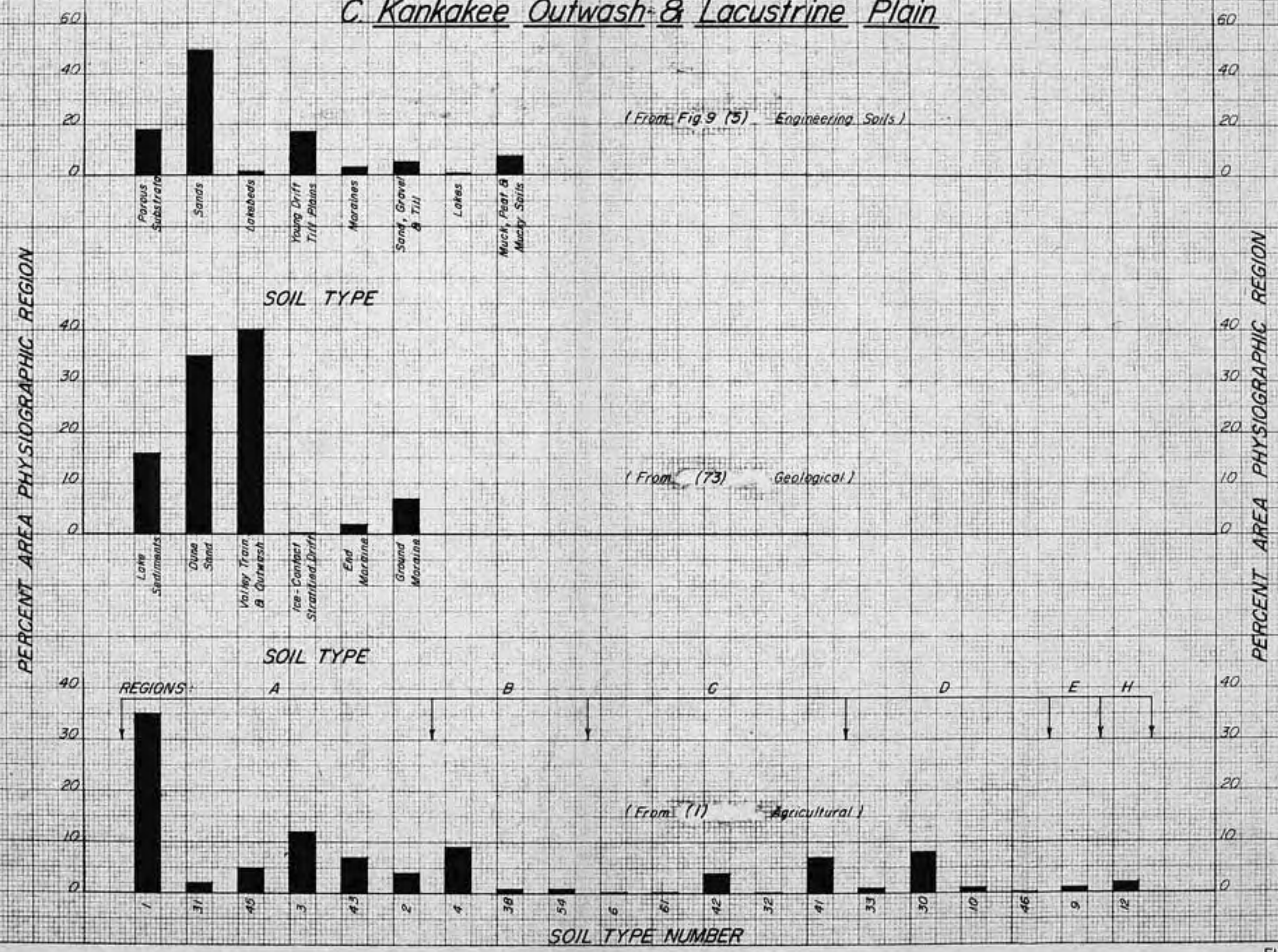


FIGURE C-3

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20x20 PER INCH  
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# I. Northern Lake And Moraine Region

## D. Steuben Morainal Lake Area

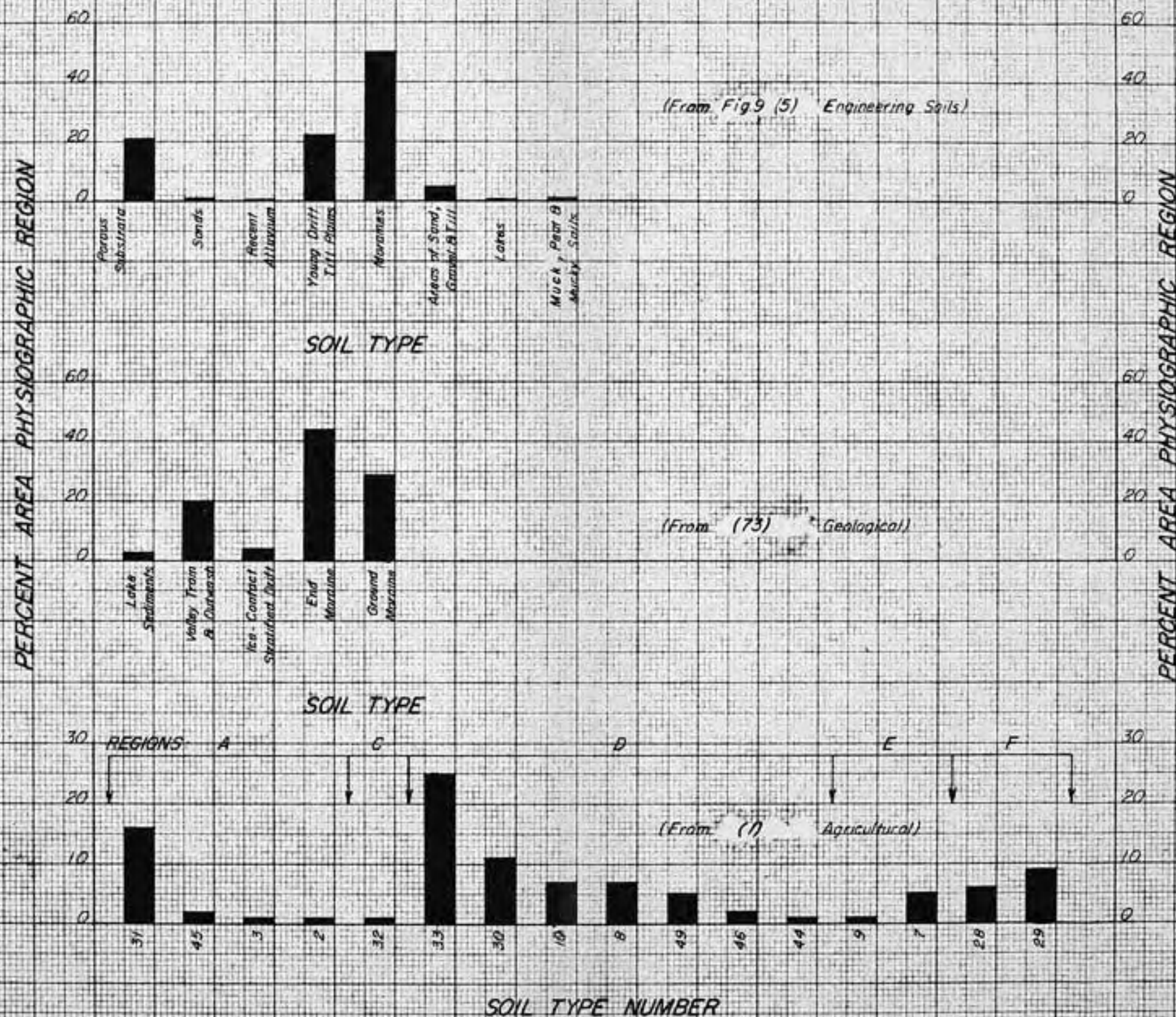


FIGURE C-4



# I. Northern Lake And Moraine Region

## E. Maumee Lacustrine Plain

PERCENT AREA PHYSIOGRAPHIC REGION

100

80

60

40

20

0

100

80

60

40

20

0

80

60

40

20

0

(From Fig.9 (5) Engineering Soils)

SOIL TYPE

(From (73) Geological)

SOIL TYPE

REGIONS: B

F

(From (1) Agricultural)

SOIL TYPE NUMBER

PERCENT AREA PHYSIOGRAPHIC REGION

100

80

60

40

20

0

100

80

60

40

20

0

80

60

40

20

0

PERCENT AREA PHYSIOGRAPHIC REGION

Porous  
Substrata

Sands

Lakebeds

Recent  
Alluvium

Young Drift  
Till Plains

Lake  
Sediments

End  
Moraine

Ground  
Moraine

48

58

28

29

FIGURE C-5



## 2. Tipton Till Plain

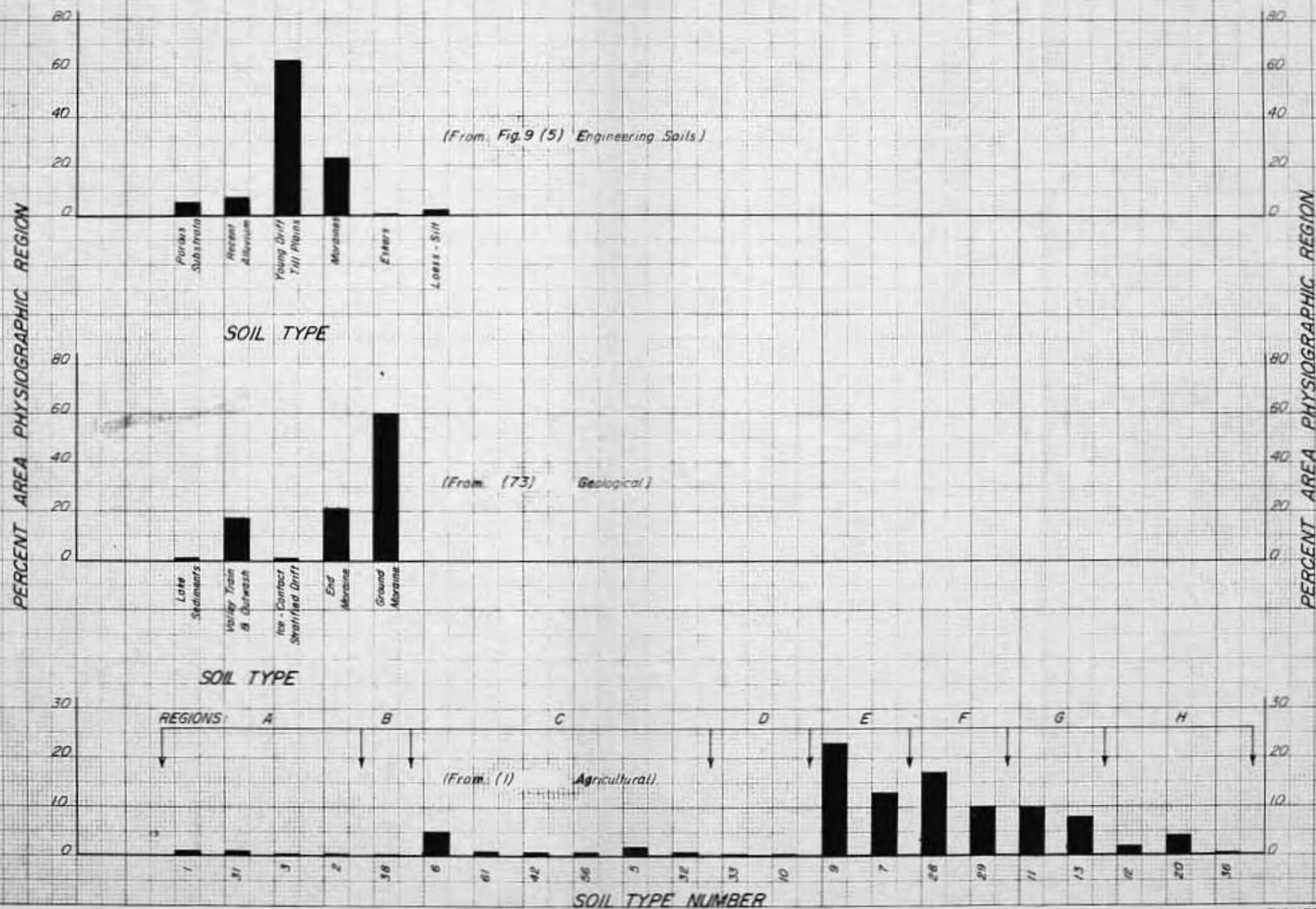


FIGURE C-6

### 3. Dearborn Upland

PERCENT AREA  
PHYSIOGRAPHIC REGION

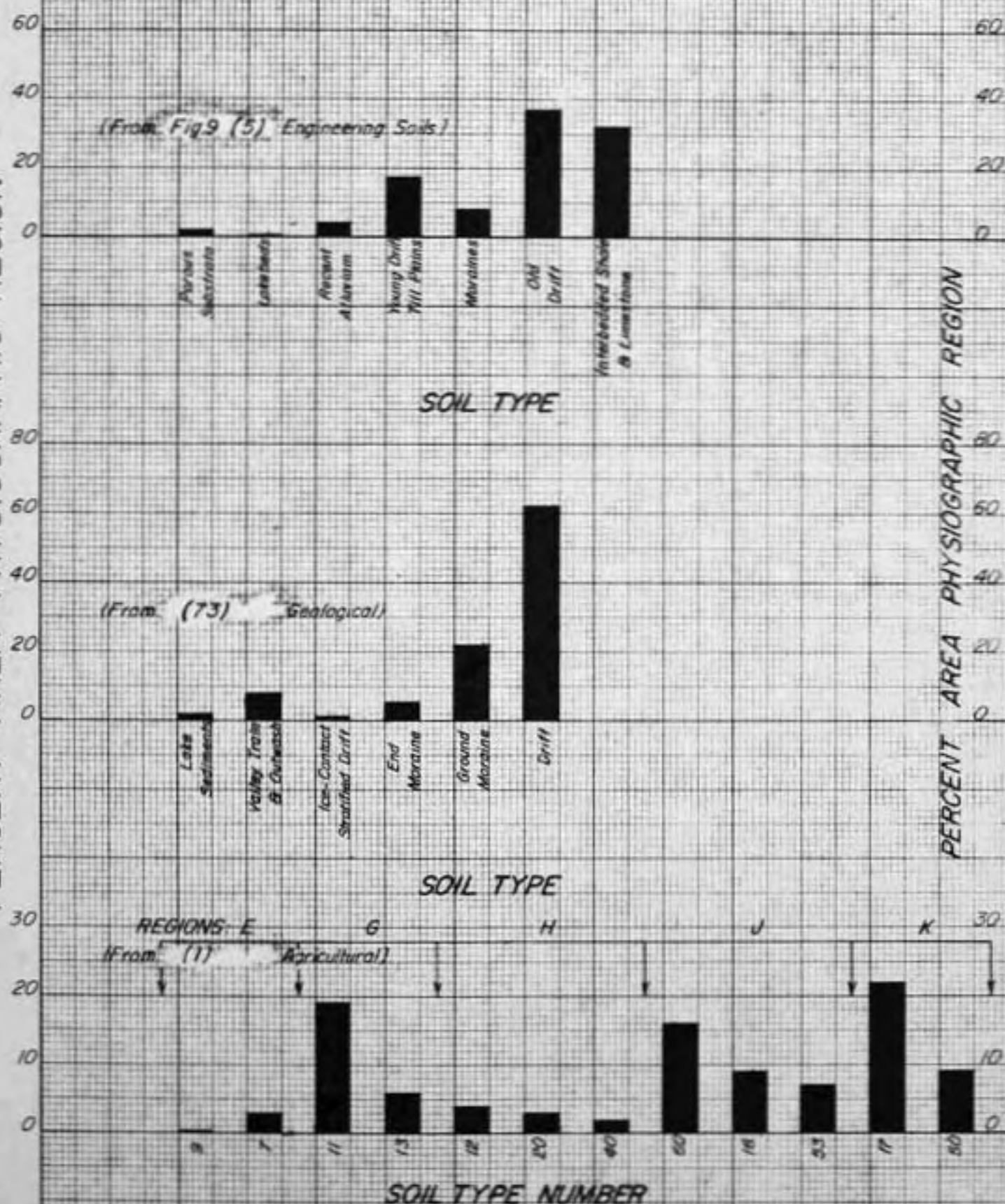


FIGURE C-7



# 4. Muscatatuck Regional Slope

PERCENT AREA PHYSIOGRAPHIC REGION

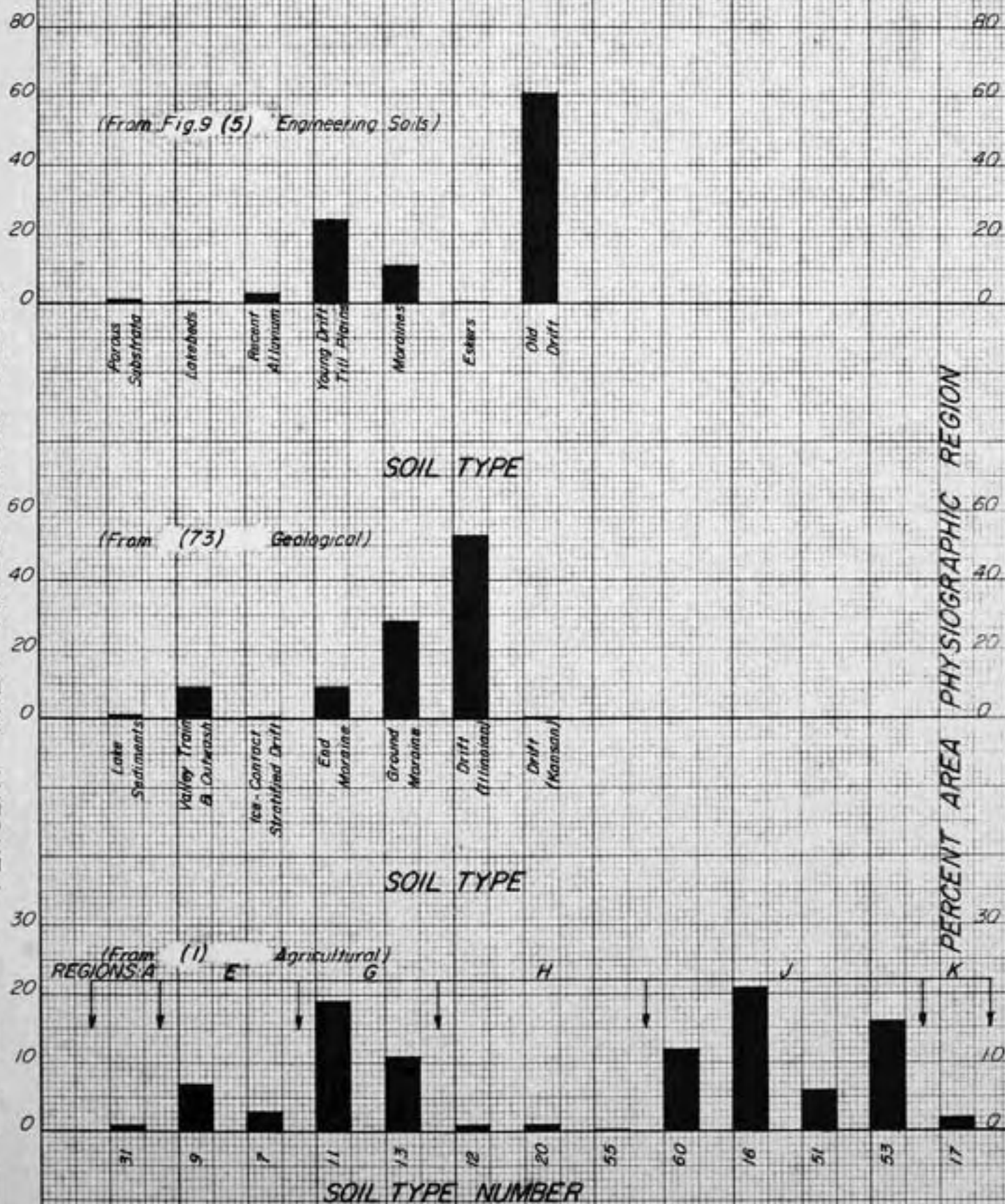


FIGURE C-8



# 5. Scottsburg Lowland

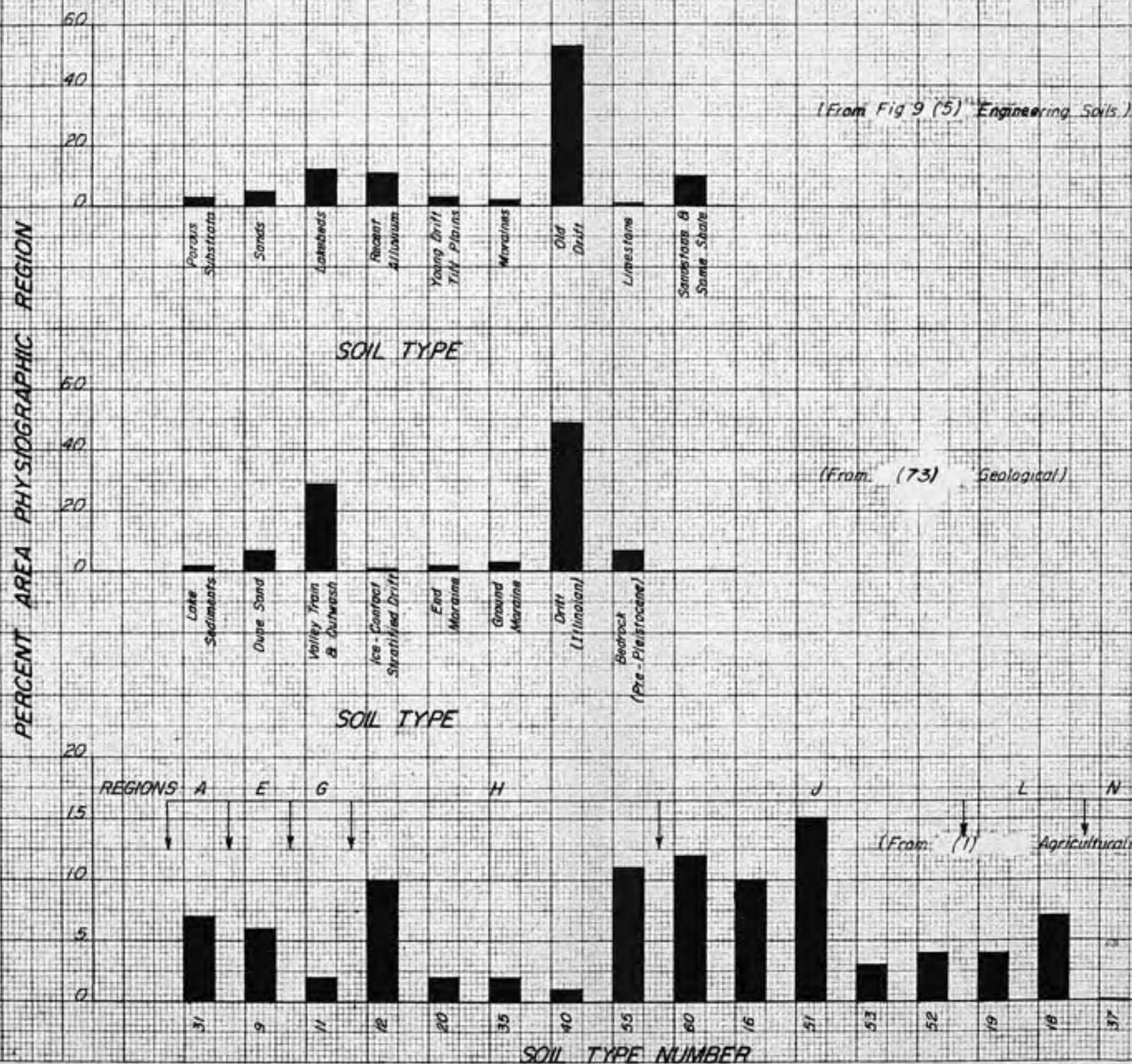


FIGURE C-9



## 6. Norman Upland

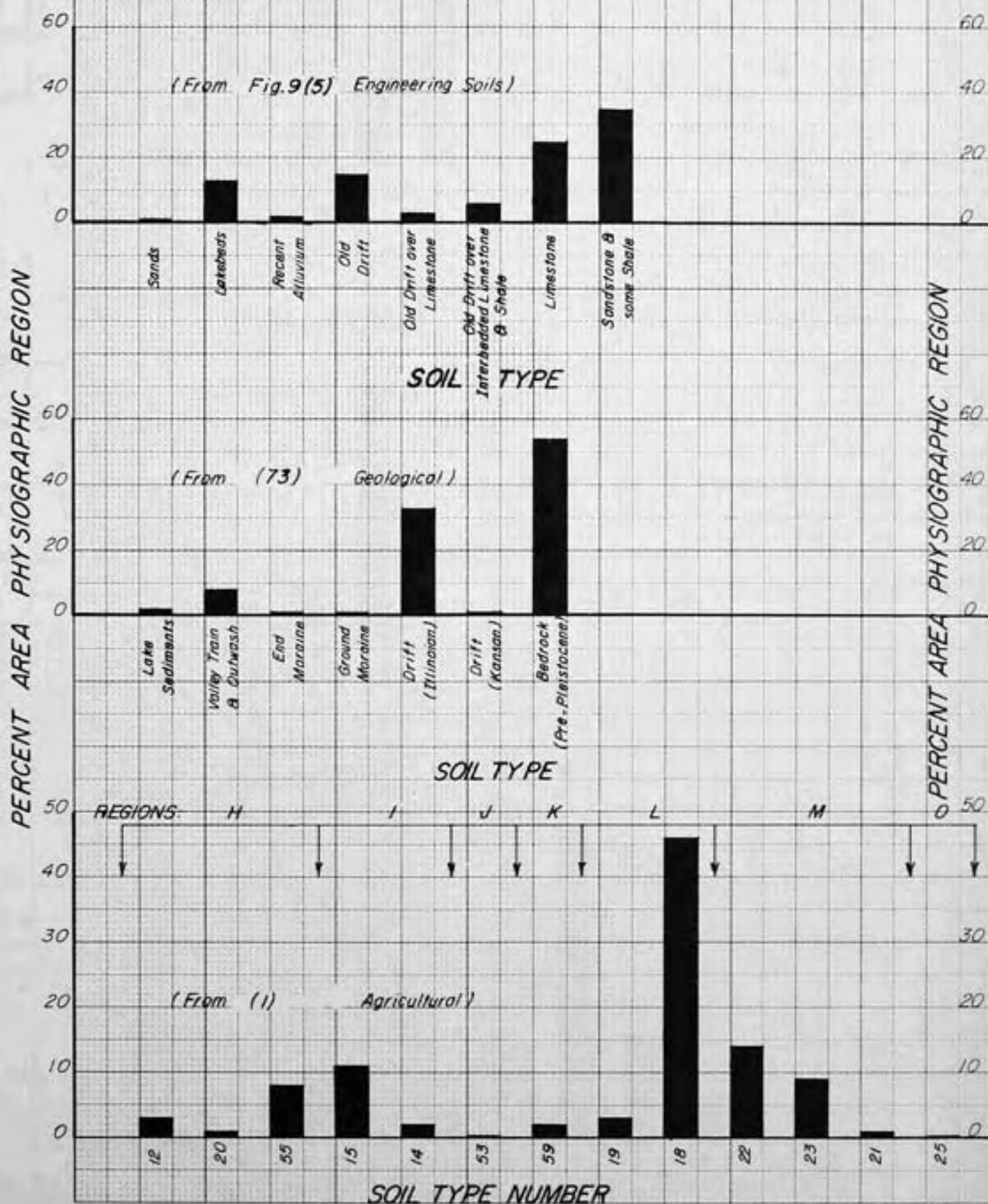


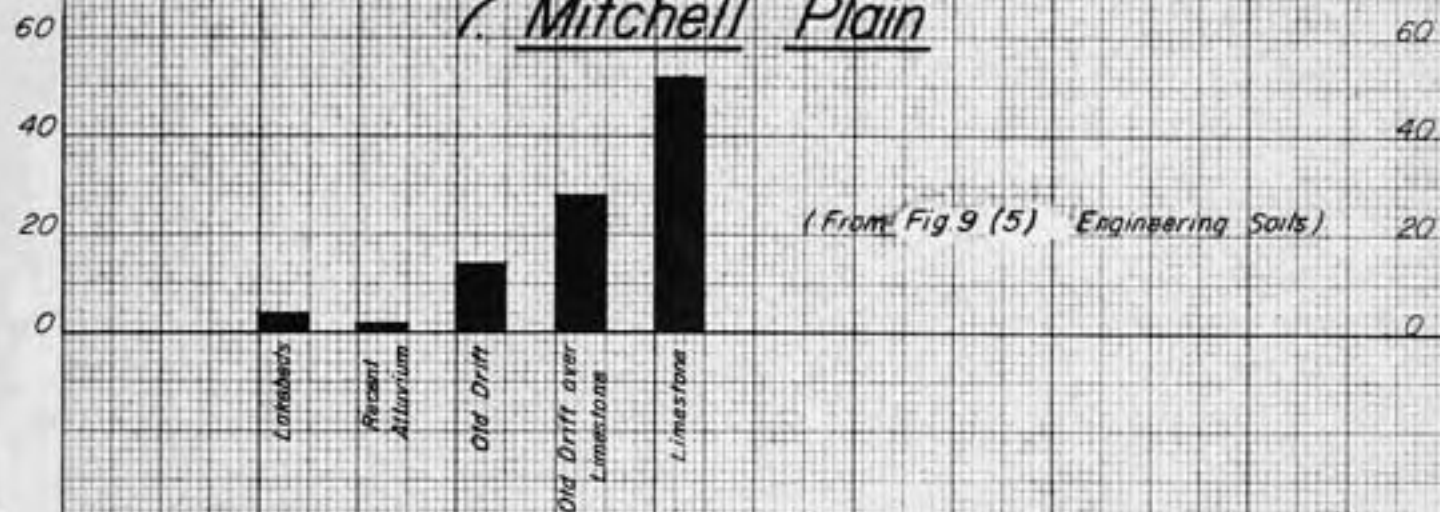
FIGURE C-10



# 7. Mitchell Plain

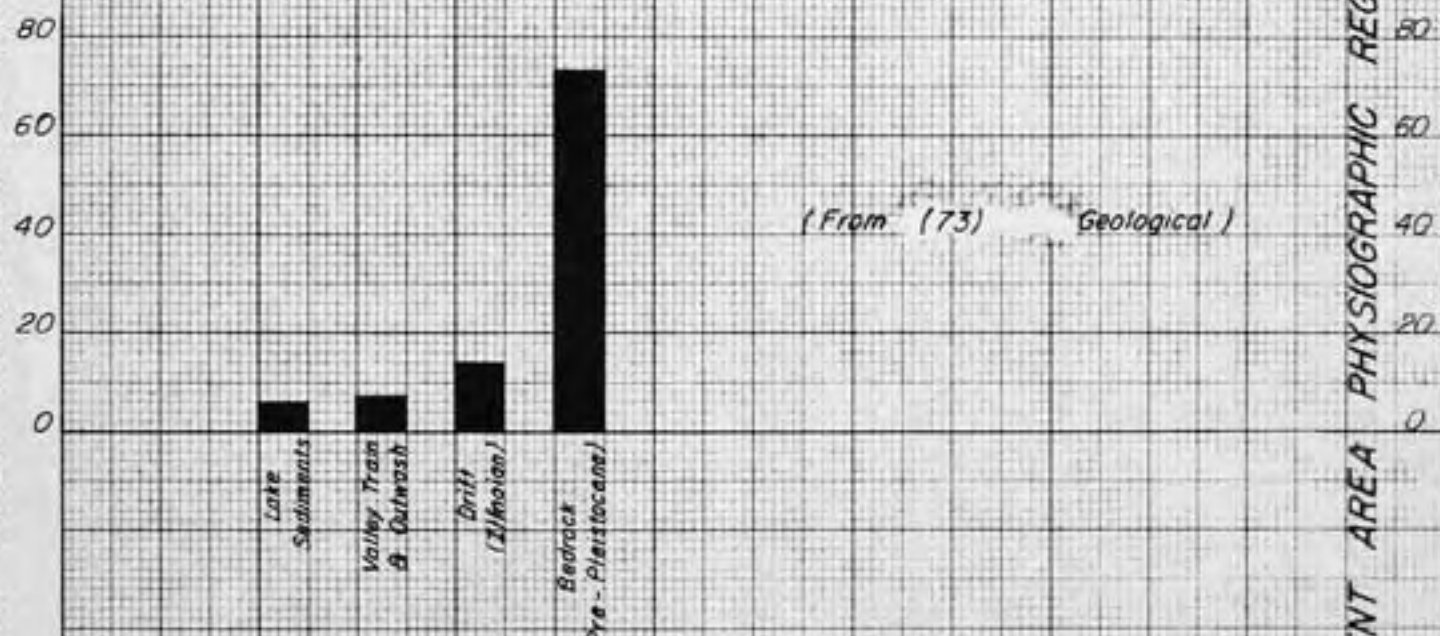
(From Fig 9 (5) Engineering Soils)

PERCENT AREA PHYSIOGRAPHIC REGION



## SOIL TYPE

(From (73) Geological)



REGIONS: H

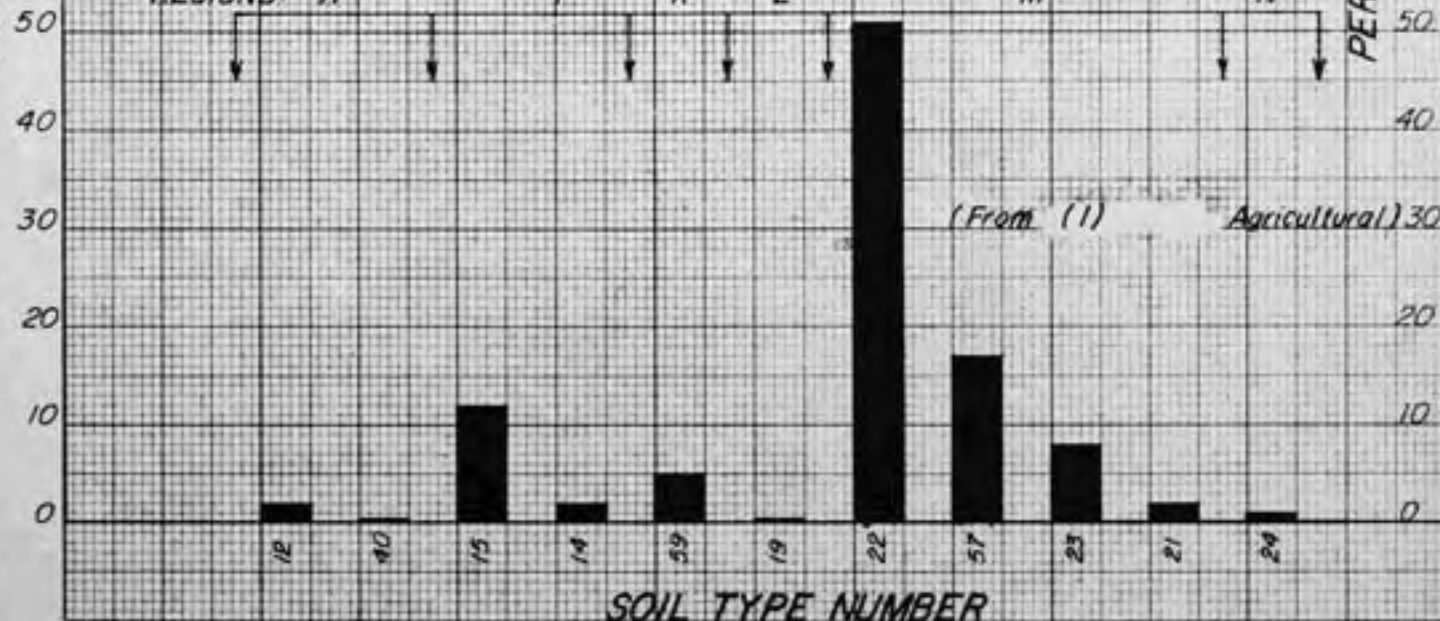
## SOIL TYPE

K

L

M

N



(From (1) Agricultural)

FIGURE C-11

# 8. Crawford Upland

PERCENT AREA PHYSIOGRAPHIC REGION

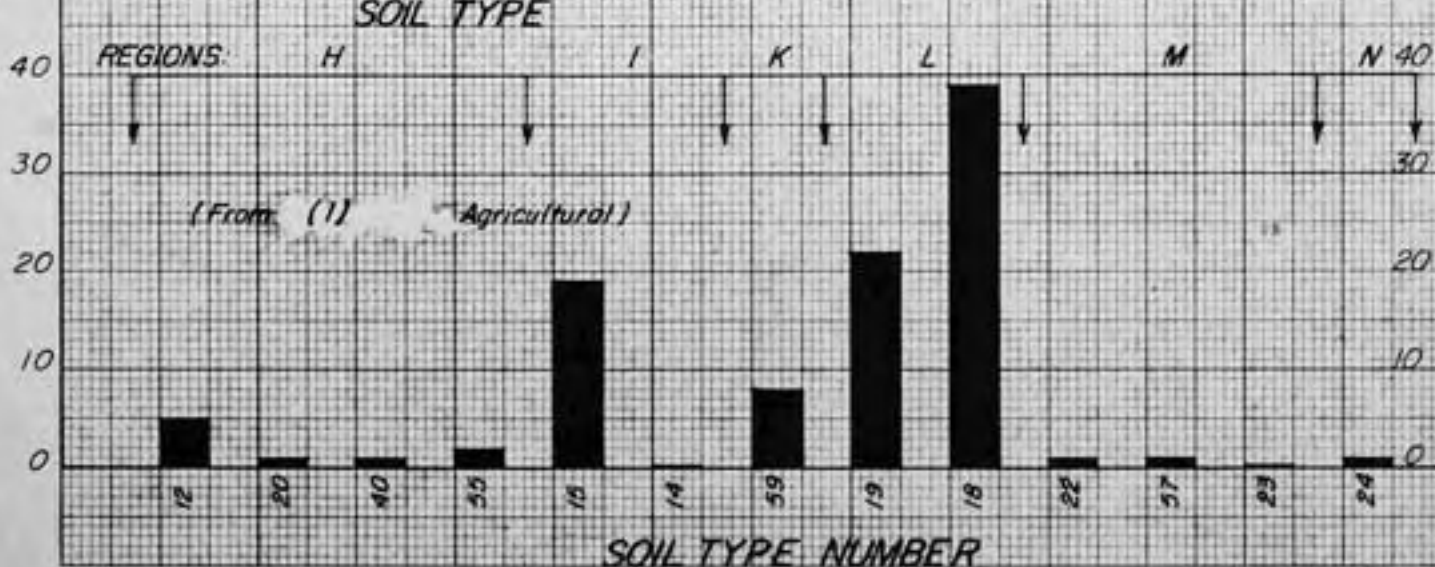
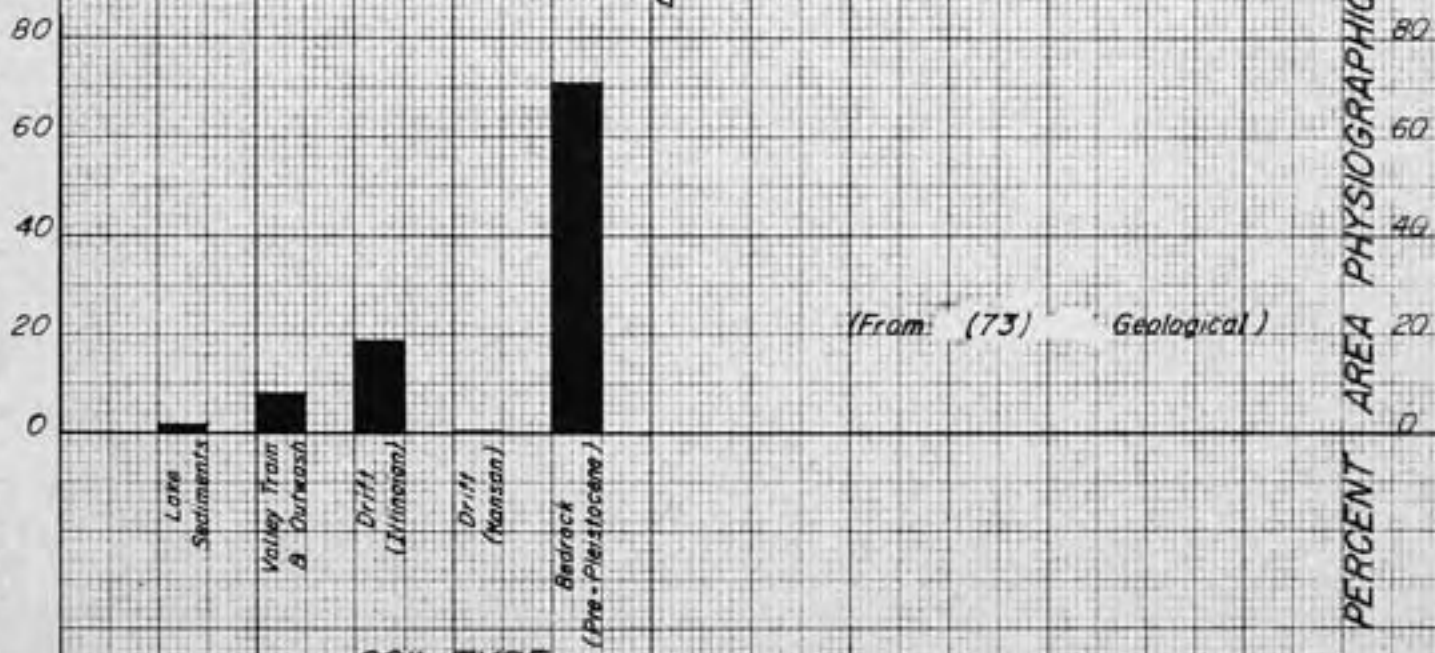
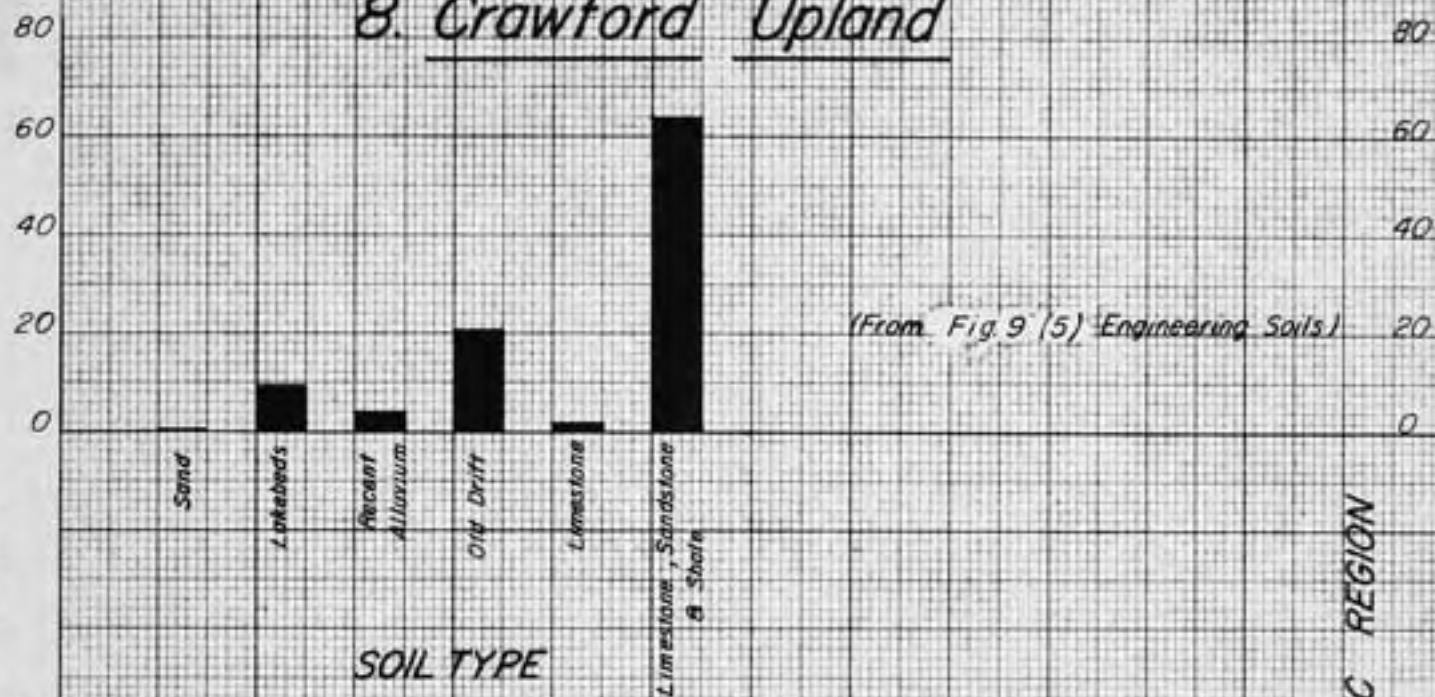
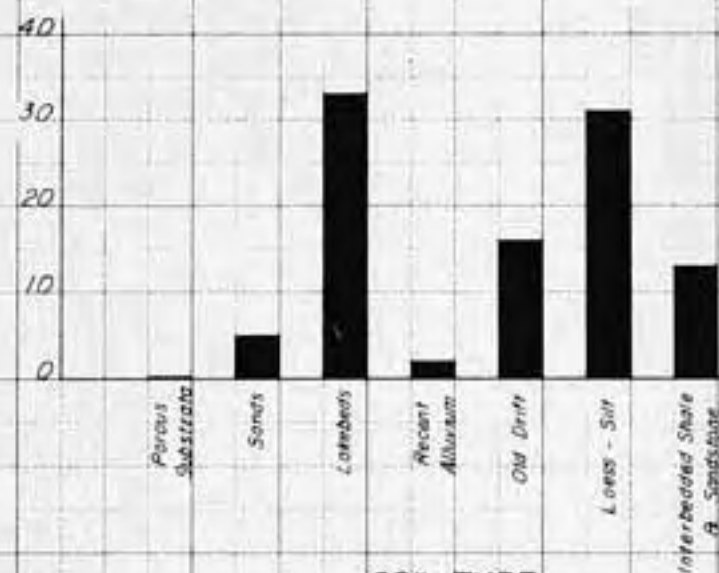


FIGURE C-12.

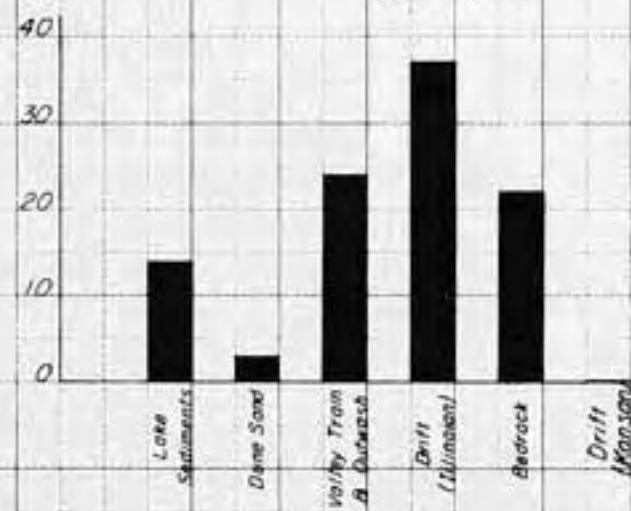


# 9. Wabash Lowland

PERCENT AREA PHYSIOGRAPHIC REGION



SOIL TYPE



SOIL TYPE

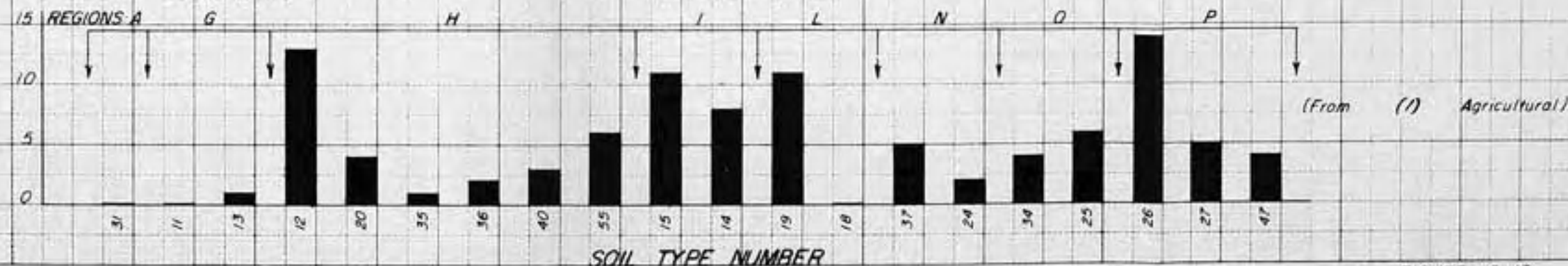


FIGURE C-13

APPENDIX D  
STATISTICAL RELATIONSHIPS

## APPENDIX D

Section 1 Ungrouped Data

From (50) pp. 117 and 118 (Miller and Freund)

$$\text{MEAN, } \bar{x} = \frac{\sum_{i=1}^n x_i}{n}$$

$$\text{STANDARD DEVIATION, } s = \sqrt{\frac{\sum_{i=1}^n (x_i - \bar{x})^2}{n-1}}$$



Section 2 Grouped Data

From (50) pp. 121

$$\text{MEAN, } \bar{x} = \frac{\sum_{i=1}^k x_i f_i}{n}$$

$$\text{STANDARD DEVIATION, } S = \sqrt{\frac{n \cdot \sum_{i=1}^k x_i^2 f_i - \left( \sum_{i=1}^k x_i f_i \right)^2}{n(n-1)}}$$

Section 3 Linear Regression

From (14) (Draper and Smith)

Linear Regression: Fitting a straight line page 7

$$\text{Model: } y = \beta_0 + \beta_1 x + \epsilon$$

$$\text{Prediction Equation: } \hat{y} = b_0 + b_1 x$$

Normal Equations:

$$(1) \quad b_0 n + b_1 \sum_{i=1}^n x_i = \sum_{i=1}^n y_i$$

$$(2) \quad b_0 \sum_{i=1}^n x_i + b_1 \sum_{i=1}^n x_i^2 = \sum_{i=1}^n x_i y_i$$

Parameter Estimates:

$$b_1 = \frac{\sum x_i y_i - \frac{(\sum x_i)(\sum y_i)}{n}}{\sum x_i^2 - \frac{(\sum x_i)^2}{n}}$$

$$b_0 = \bar{y} - b_1 \bar{x}$$

$$\text{where } \bar{x} = \frac{\sum x_i}{n} \text{ and } \bar{y} = \frac{\sum y_i}{n}$$

Analysis of Variance Table, Anova page 15

Source	Sum of Squares	Degrees of Freedom	Mean Square
Regression	$b_1 \left[ \sum x_i y_i - \frac{(\sum x_i)(\sum y_i)}{n} \right]$	1	$MS_R$
About Regression (residual)	By Subtraction	$n-2$	$s^2 = \frac{(ss)}{(n-2)}$
About Mean (Total Corrected for Mean)	$\sum y_i^2 - \frac{(\sum y_i)^2}{n}$	$n-1$	

Section 3 (cont'd)F-Test for Significance of Regression    page 24

$$F = \frac{MS_R}{s^2}$$

$$F_{(1, n-2, 1-\alpha)} \quad (\text{Tabulated Values} \quad \text{pages 306 and 307})$$

If  $F > F_{(1, n-2, 1-\alpha)}$ , we reject the hypothesis  $H_0: \beta_1 = 0$

running the risk of less than  $(1-\alpha)$  of being wrong. Therefore, the regression is considered to be significant, within the risks assumed.

Lack of Fit and Pure Error    page 26

$$F = \frac{MS_L}{s_e^2}$$

$$\text{where } s_e^2 = \left[ \frac{\sum_{i=1}^k \sum_{u=1}^{n_i} (Y_{iu} - \bar{Y}_i)^2}{\sum_{i=1}^k n_i - k} \right]$$

If  $F < F_{\text{Tabulated}}$ , we say there is no significant lack of fit for the prediction equation, within the risks assumed.

(1-α) Confidence Limits for True Mean Value of Y    page 21

$$\hat{y}_k \pm t_{(n-2, 1-\frac{\alpha}{2})} \text{ est. s.e. } (\hat{y}_k)$$

$$\text{where est. s.e. } (\hat{y}_k) = \sqrt{s^2 \left[ \frac{1}{n} + \frac{(x_k - \bar{x})^2}{\sum (x_i - \bar{x})^2} \right]}$$

# Section 4 Multiple Regression

From (14)

Multiple Regression: Two Independent Variables page 104

$$\text{Model: } y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \epsilon$$

For the quadratic, we simply substitute  $x_1^2$  for  $x_2$

$$\text{Prediction Equation: } \hat{y} = b_0 + b_1 x_1 + b_2 x_1^2$$

we can drop the subscript 1

$$y = b_0 + b_1 x + b_2 x^2$$

Normal Equations:

$$(1) b_0 n + b_1 \sum x + b_2 \sum x^2 = \sum y$$

$$(2) b_0 \sum x + b_1 \sum x^2 + b_2 \sum x^3 = \sum xy$$

$$(3) b_0 \sum x^2 + b_1 \sum x^3 + b_2 \sum x^4 = \sum x^2 y$$

Parameter Estimates:

$$b = \begin{bmatrix} b_0 \\ b_1 \\ b_2 \end{bmatrix} = (x'x)^{-1} x'y$$

By matrix procedures chapter 2.

Analysis of Variance Table, Anova page 115

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Total (Uncorrected)	n	$\sum y_i^2$		
Mean ( $b_0$ )	1	$(\sum y_i)^2/n$		
Total (corrected)	n-1	$\sum y_i^2 - (\sum y_i)^2/n$		
Regression/ $b_0$	p-1	$b'x'y - (\sum y_i)^2/n$	$\frac{ss \text{ Reg.}}{p-1}$	$\frac{Ms \text{ Reg.}}{s^2} = F$
Residual	$[(n-1)-(p-1)]$	$SST - SSR$	$s^2 = \frac{SS \text{ Res.}}{[(n-1)-(p-1)]}$	

Section 4 (cont'd)

where  $P$  is the number of parameters to be estimated, which is three (3) in this situation.

F-Test for Significance of Regression page 115

$$F = \frac{\text{Mean Square Regression}}{\text{Mean Square Residual}} = \frac{MS_{\text{Reg.}}}{s^2}$$

$$F_{(P-1, [(n-1)-(P-1)], 1-\alpha)} \quad (\text{Tabulated values pages 306 and 307})$$

If  $F > F_{(P-1, [(n-1)-(P-1)], 1-\alpha)}$ , we reject the hypothesis

$H_0: \beta_1 = 0$  running the risk of less than  $(1-\alpha)$  of being wrong. Therefore, the regression is considered to be significant, within the risks assumed.

Sequential F-Test Criterion (Showing the Additional Contribution of  $x^2$ 

Given that  $x$  is already in the Equation) page 119

The ANOVA Table shown above is modified as follows:

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Total (corrected)	$n-1$	$\sum Y_i^2 - (\sum Y_i)^2/n$		
Regression $ b_0$	$P-1$	$b'x'y - (\sum Y_i)^2/n$	$\frac{ss_{\text{Reg.}}}{p-1}$	$\frac{MS_{\text{Reg.}}}{s^2}$
due to $b_1   b_0$	1	$b_1(\sum x_i y_i - \frac{(\sum x_i)(\sum y_i)}{n})$	$\frac{ssR(b_1   b_0)}{1}$	$\frac{MS(b_1   b_0)}{s^2}$
due to $b_2   b_1, b_0$	1	By subtraction	$\frac{ssR(b_2   b_1, b_0)}{1}$	$\frac{MS(b_2   b_1, b_0)}{s^2}$
Residual	$[(n-1)-(P-1)]$	$SST - SSR$	$s^2 = \frac{ss_{\text{Res.}}}{[(n-1)-(P-1)]}$	



Section 4 (cont'd)

$$F = \frac{\text{Mean Square Regression due to } b_2 | b_1, b_0}{\text{Mean Square Residual}} = \frac{MS(b_2 | b_1, b_0)}{s^2}$$

$$F_{(1, [(n-1)-(P-1)], 1-\alpha)} \quad (\text{Tabulated Values pages 306 and 307})$$

If  $F > F_{(1, [(n-1)-(P-1)], 1-\alpha)}$ , the addition of the second term,  $x^2$ , has been worthwhile, within the risks assumed.

(1- $\alpha$ ) Confidence Limits for the True Mean Value of Y Page 121

$$\bar{y} \pm t_{[(n-p-1), 1-\frac{\alpha}{2}]} \cdot s \sqrt{x_0' C x_0}$$

APPENDIX E

DETAILED STATISTICAL RELATIONSHIPS FOR TYPICAL  
PROFILES NOS. 1, 2 AND 3 OF THE CALUMET LACUSTRINE PLAIN

Table E-1

1. Northern Lake and Moraine Region  
A. Calumet Lacustrine Plain

Typical Profile No. 1

Landform: Dune Sand

Data for Statistical Soil Classification

	DUNE SAND - STRATUM A								LAKEBED - STRATUM B								
	% Passing No. 40 Sieve	% Passing No. 200 Sieve	% Sand	% Silt	% Clay	Liquid Limit	Plasti- city Index	Classification		% Passing No. 200 Sieve	% Sand	% Silt	% Clay	Liquid Limit	Plasti- city Index	Classification	
								Textural	AASHTO							Textural	AASHTO
Average Value																	
(Method 1) $\bar{X}_1$	85.7	5.9	94.1	4.0	1.9	N.P.	N.P.	Sand	A-3(0)	87.6	12.4	58.6	29.0	28.4	12.5	Silty Clay A-6(9)	Loam
(Method 2) $\bar{X}_2$	91.1	3.5	96.5	2.4	1.1	N.P.	N.P.	Sand	A-3(0)	87.1	12.9	54.7	32.4	28.4	12.5	Silty Clay A-6(9)	
(Method 3) $\bar{X}_3$	91.5	3.2	96.8	2.4	0.8	N.P.	N.P.	Sand	A-3(0)	87.8	12.2	55.0	32.8	28.4	12.5	Silty Clay A-6(9)	
Standard Deviation																	
(Method 1) $S_1$	19.3	6.3	6.3	4.5	3.4	N.P.	N.P.			11.9	11.9	11.8	14.3	4.4	4.1		
(Method 2) $S_2$	14.7	5.0	5.0	3.4	2.6	N.P.	N.P.			12.4	12.4	11.6	14.3	4.2	4.0		
(Method 3) $S_3$	14.1	4.6	4.6	3.3	2.2	N.P.	N.P.			11.8	11.8	10.3	12.9	4.0	3.7		
Maximum Value, Max $\bar{X}_1$	100	20	100	19	13	N.P.	N.P.			100	34	80	55	38	21		
Minimum Value, Min $\bar{X}_1$	1	0	80	0	0	N.P.	N.P.			66	0	42	6	21	7		
Range R	99	20	20	19	13	N.P.	N.P.			34	34	38	49	17	14		

SECTION 1

TYPICAL PROFILE NO. 1

# I. NORTHERN LAKE AND MORaine REGION

## A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 1

LANDFORM: DUNE SAND

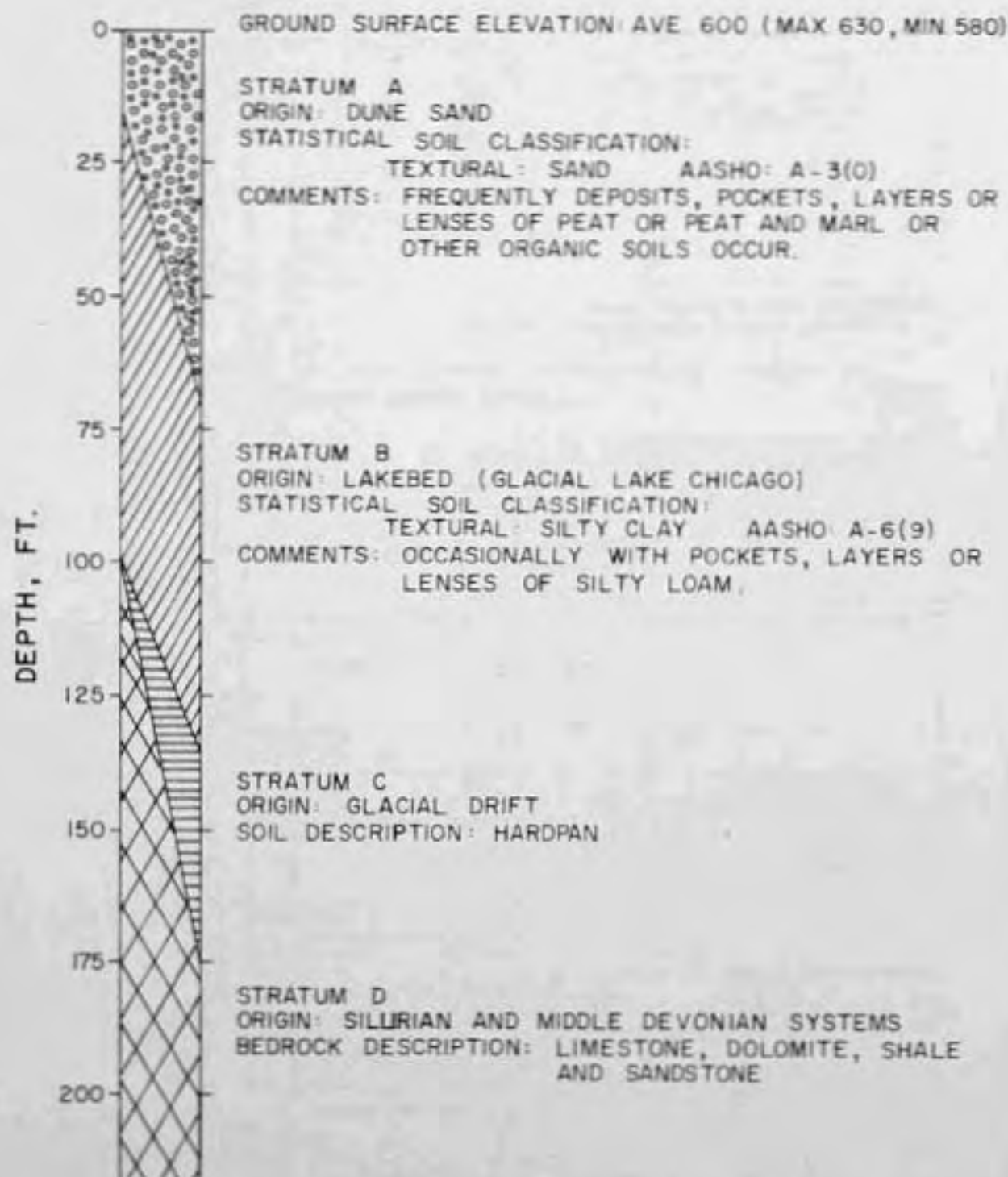


FIGURE E-1



FIGURE E-2

I. NORTHERN LAKE AND MORaine REGION  
A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 1  
LANDFORM - DUNE SAND

STRATUM A  
STATISTICAL SOIL CLASSIFICATION -

TEXTURAL SAND  
AASHTO - A-3 (3)

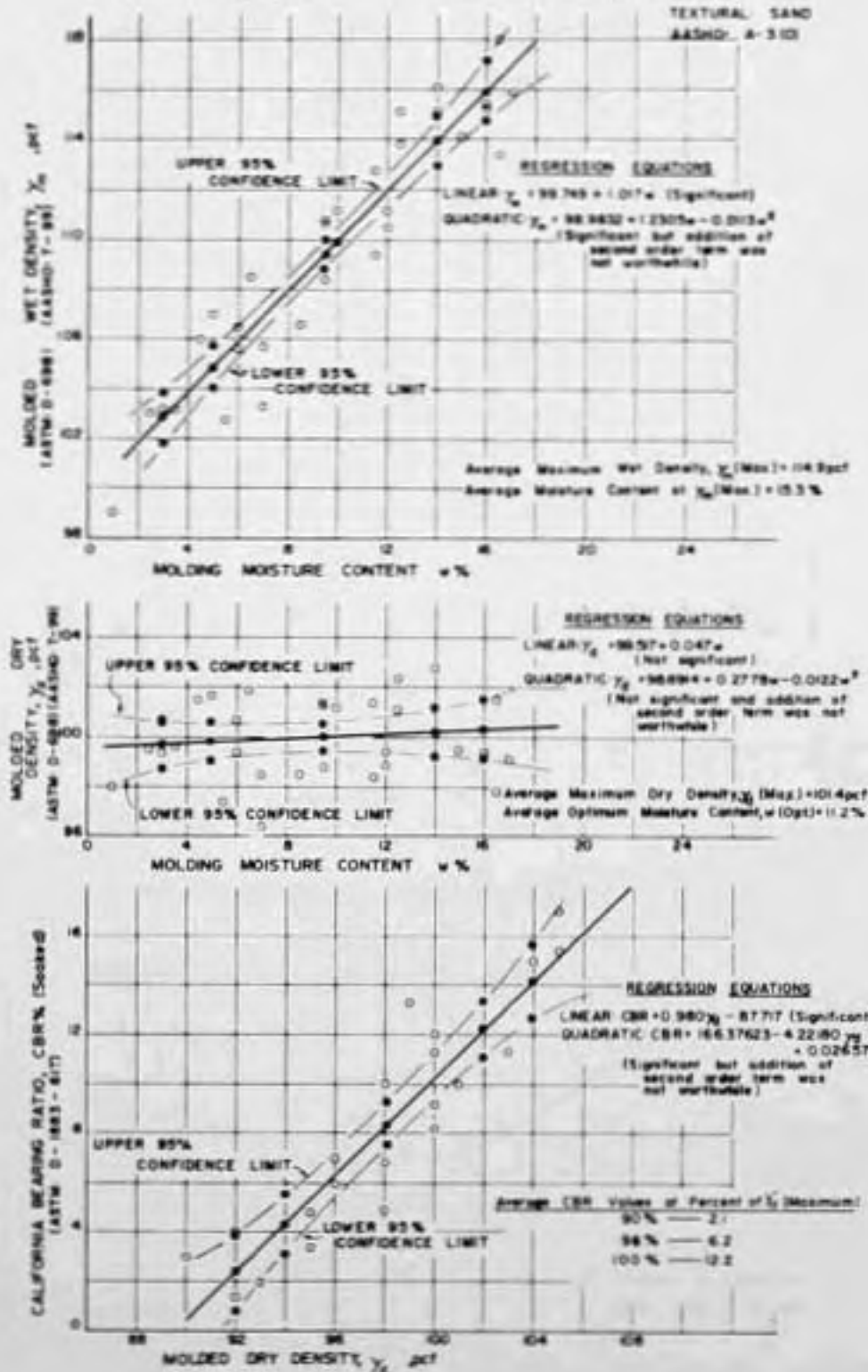


FIGURE E-3  
1. NORTHERN LAKE AND MORaine REGION  
A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 1

STRATUM : B

ORIGIN : LAKEBED

STATISTICAL SOIL CLASSIFICATION

TEXTURAL : SILTY CLAY

AASHTO : A-6(9)

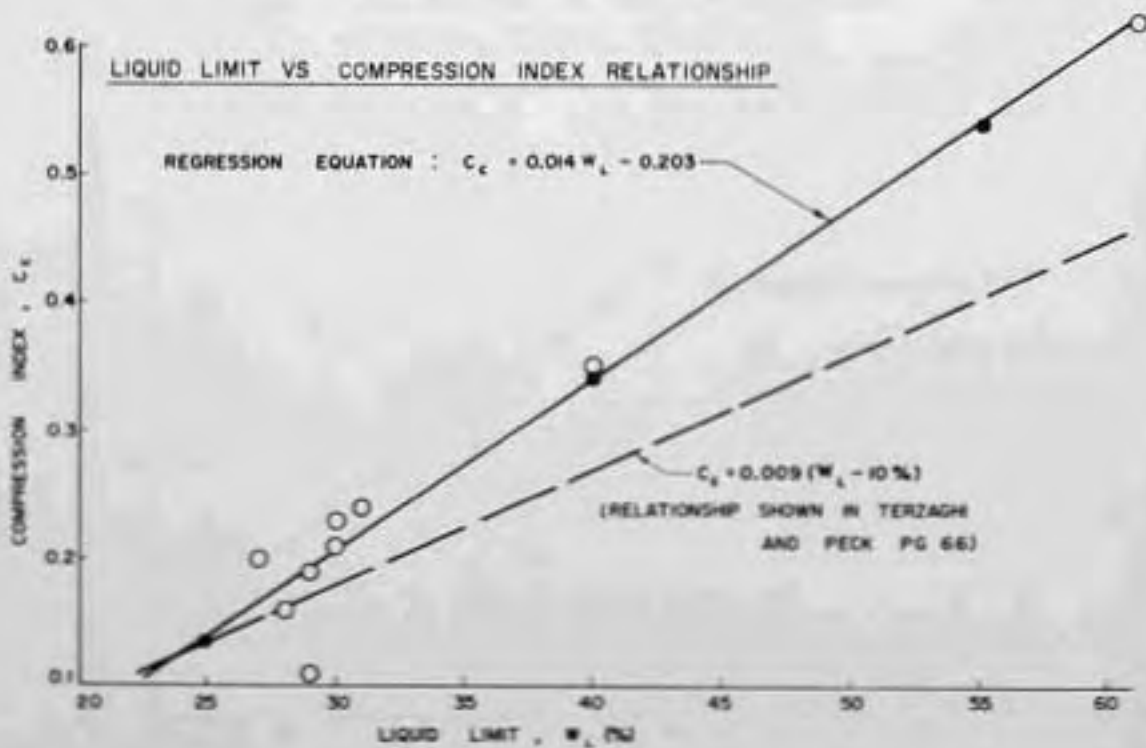
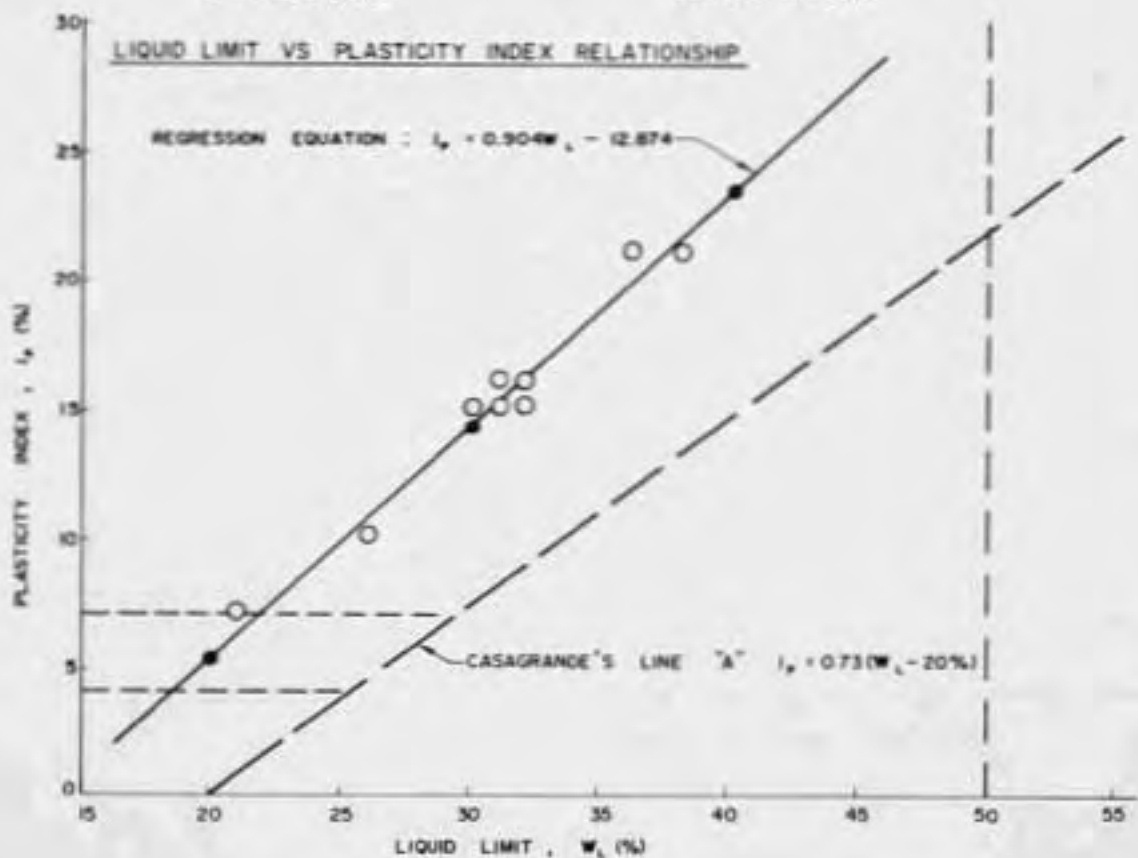
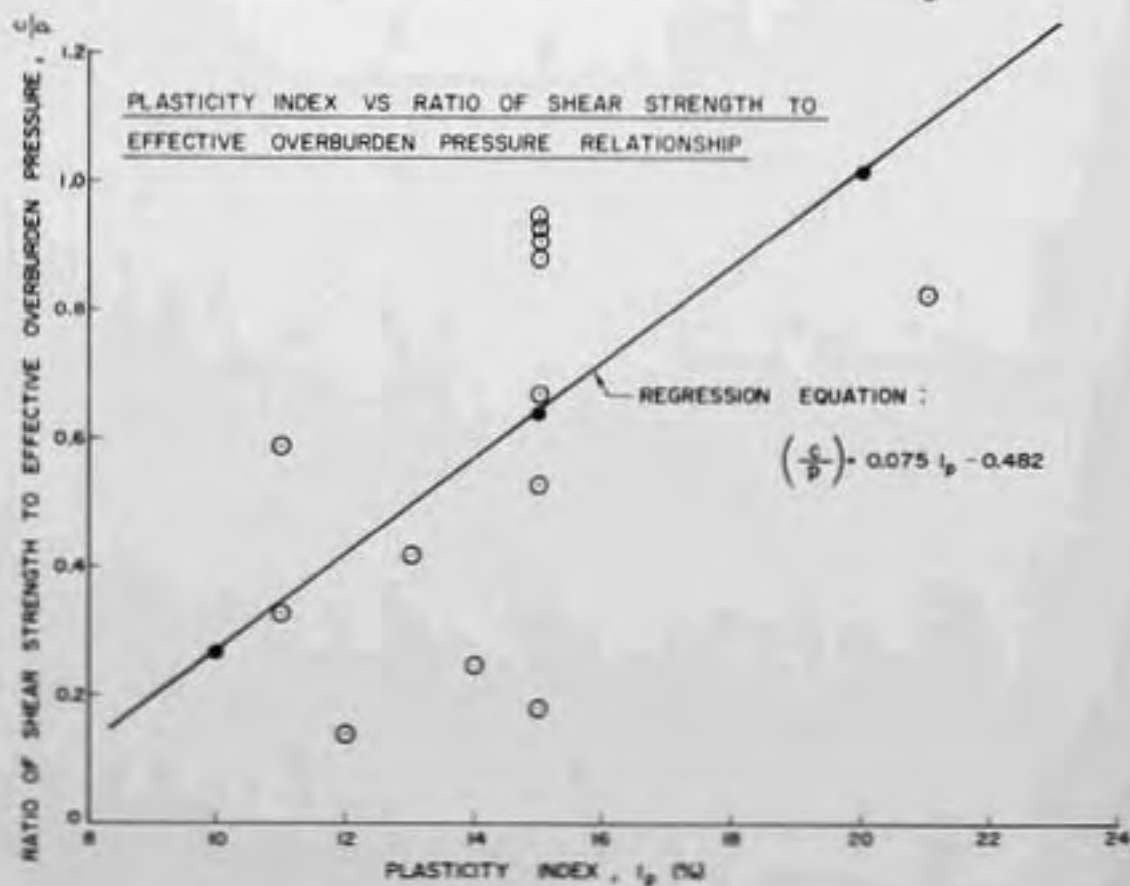
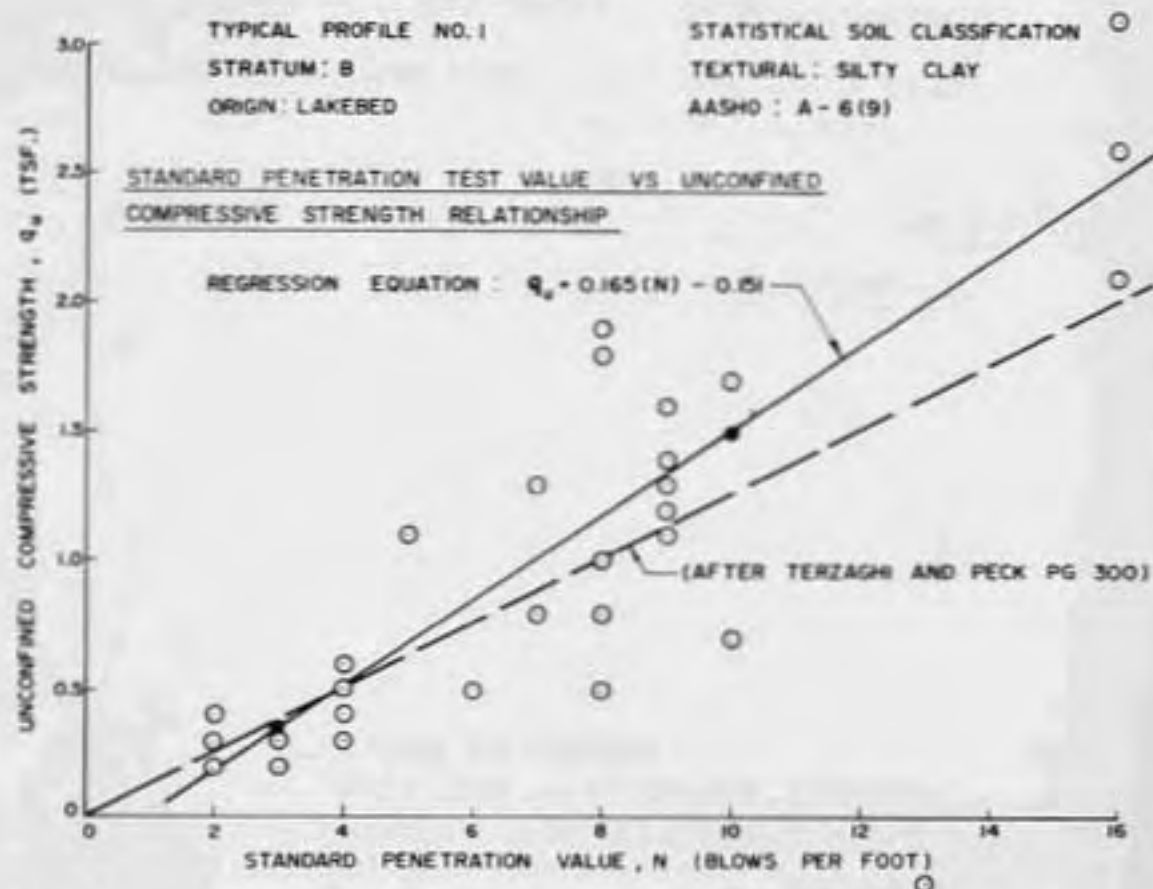


FIGURE E-4  
I. NORTHERN LAKE AND MORaine REGION  
A. CALUMET LACUSTRINE PLAIN



# I. NORTHERN LAKE AND MORaine REGION

## A. CALUMET LACUSTRINE PLAIN

TYPICAL SOIL PROFILE NO.1 STRATUM: B ORIGIN: LAKEBED

STATISTICAL SOIL CLASSIFICATION - TEXTURAL: SILTY CLAY  
AASHO: A-6 (9)

### NATURAL MOISTURE CONTENT VS LOG UNCONFINED COMPRESSIVE STRENGTH RELATIONSHIP

UNCONFINED COMPRESSIVE STRENGTH,  $q_u$  (TSF)

UNCONFINED COMPRESSIVE STRENGTH,  $q_u$  (TSF)

REGRESSION EQUATIONS:

LINEAR:  $\log q_u = 0.844724 - 0.037325w$

QUADRATIC:  $\log q_u = 0.5199247 - 0.0101778w$

$- 0.0005375w^2$

(AFTER C.C. LADD FIG II-10) →

NATURAL MOISTURE CONTENT,  $w$  (%)

# I. NORTHERN LAKE AND MORaine REGION

## A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 1 STRATUM: B ORIGIN: LAKEBED

STATISTICAL SOIL CLASSIFICATION - TEXTURAL: SILTY CLAY

AASHO: A-6(9)

### NATURAL MOISTURE CONTENT VS LOG STANDARD PENETRATION TEST VALUE RELATIONSHIP

STANDARD PENETRATION TEST VALUE, N (BLOWS PER FOOT)

STANDARD PENETRATION TEST VALUE, N (BLOWS PER FOOT)

REGRESSION EQUATIONS:

LINEAR:  $\log N = 1.5908 - 0.0337w$

QUADRATIC:  $\log N = 1.465879 - 0.023157w - 0.000205w^2$

NATURAL MOISTURE CONTENT,  $w$  (%)



SECTION 2

TYPICAL PROFILE NO. 2

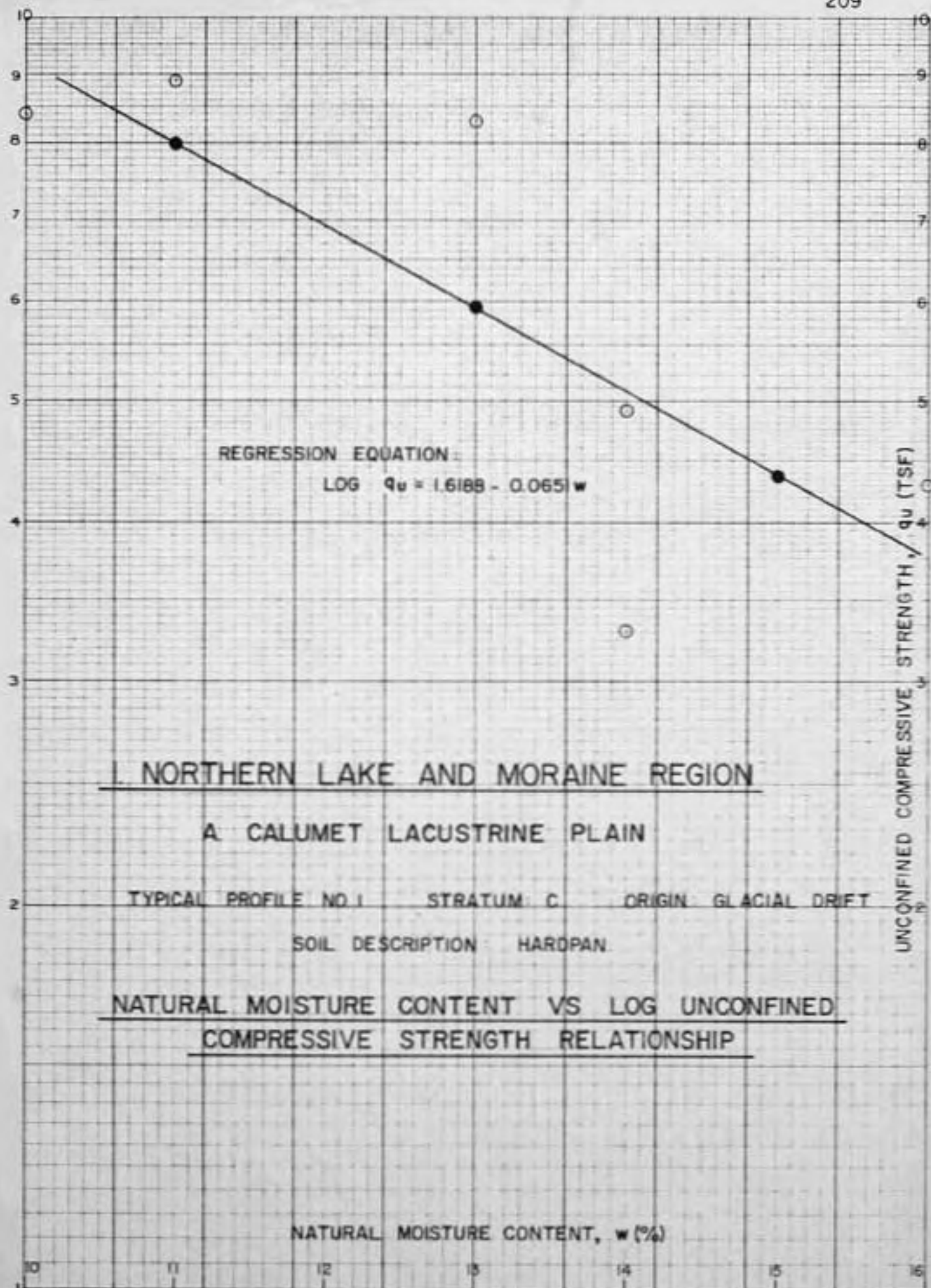


FIGURE E-7



# I. NORTHERN LAKE AND MORaine REGION

## A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 2

LANDFORM: LAKEBED

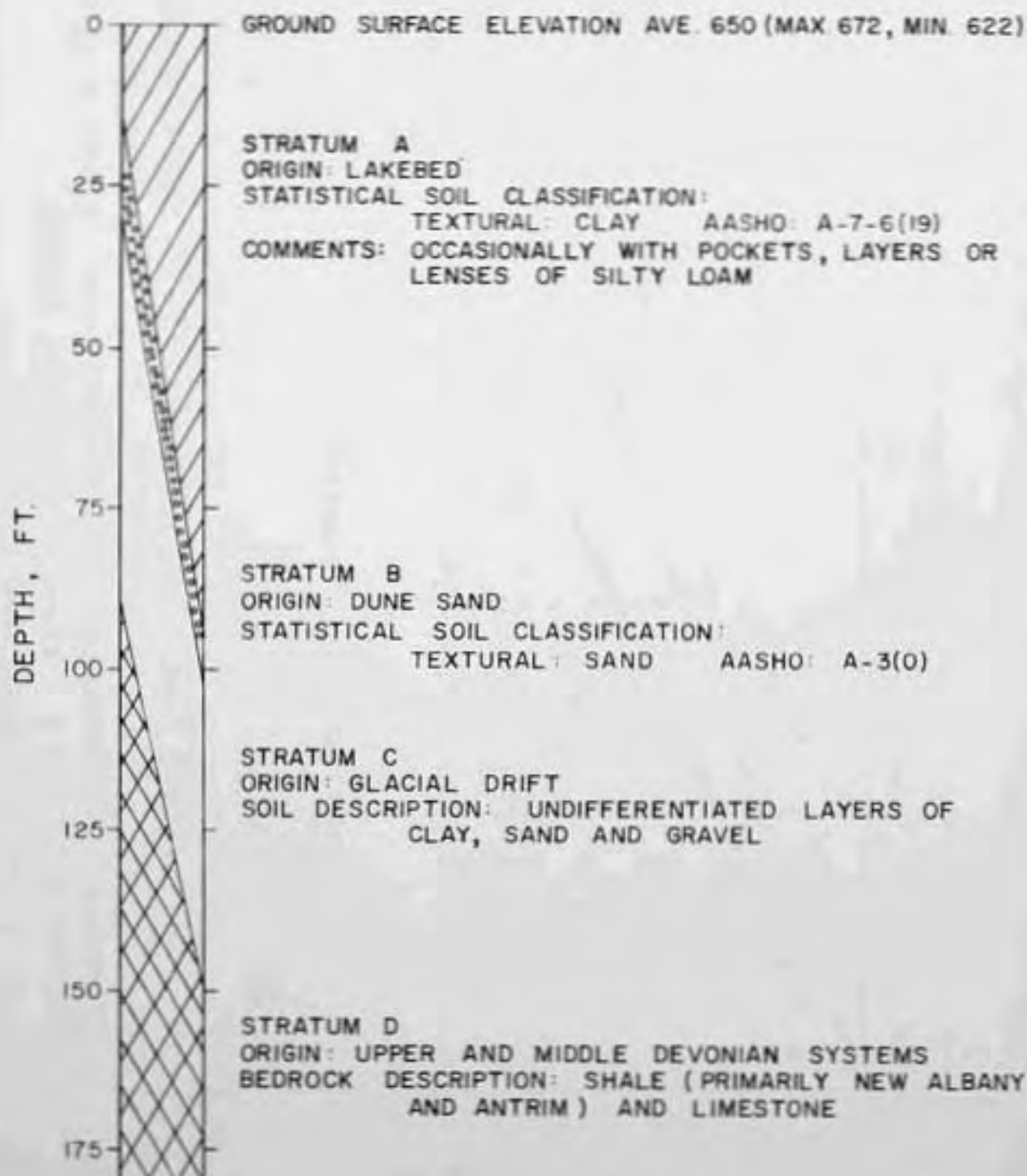


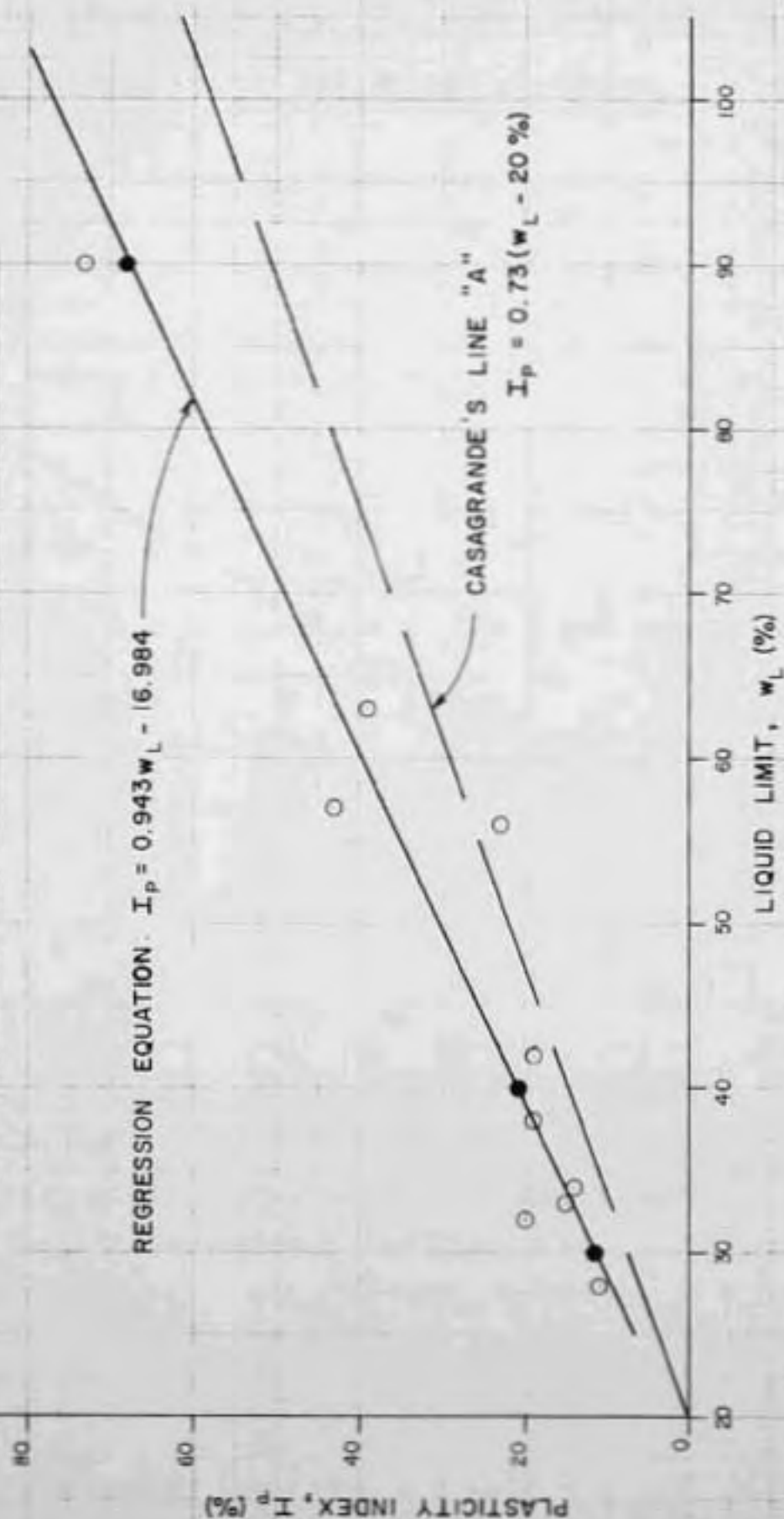
FIGURE E-8

I. NORTHERN LAKE AND MORaine REGION  
A CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 2 STRATUM: A ORIGIN: LAKEBED

STATISTICAL SOIL CLASSIFICATION - TEXTURAL: CLAY AASHO: A-7-6 (19)

LIQUID LIMIT VS PLASTICITY INDEX RELATIONSHIP





# NATURAL MOISTURE CONTENT VS LOG STANDARD

## PENETRATION TEST VALUE RELATIONSHIP

REGRESSION EQUATION:  
 $\log N = 2.494 - 0.069w$

### I. NORTHERN LAKE AND MORaine REGION

#### A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 2      STRATUM: A      ORIGIN: LAKEBED

STATISTICAL SOIL CLASSIFICATION - TEXTURAL: CLAY

AASHO: A-7-6 (19)

NATURAL MOISTURE CONTENT,  $w$ (%)

STANDARD PENETRATION TEST VALUE,  $N$  (BLOWS PER FOOT)

## I. NORTHERN LAKE AND MORaine REGION

## A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 2 STRATUM: A ORIGIN: LAKEBED

STATISTICAL SOIL CLASSIFICATION - TEXTURAL: CLAY

AASHO: A-7-6(19)

STANDARD PENETRATION TEST VALUE  
VS DEPTH      RELATIONSHIP

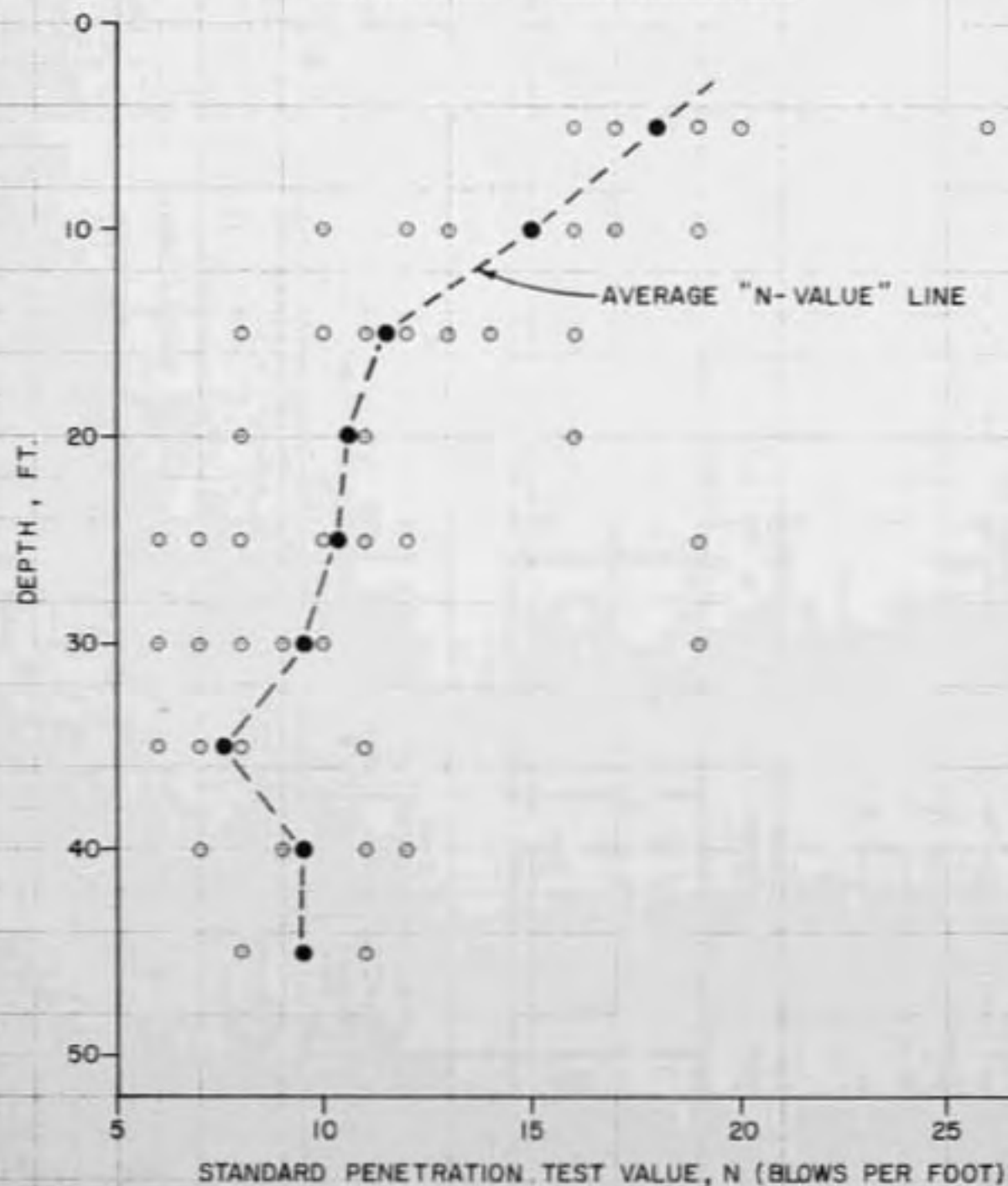


FIGURE E-11

Table E-3

## Summary of Special Test Results

## 1. Northern Lake and Moraine Region

## A. Calumet Lacustrine Plain

Sample Depth, (ft.)	Natural Moisture Content, $w$	Natural Dry Density, $\gamma_d$ (pcf)	Initial Void Ratio, $e_o$	Compression Index, $C_c$	Pre-Consolidation Stress Above Effective Stress $p_c$ (TSF)	Maximum Wet Density, $\gamma_{wMAX}$ (pcf)	Maximum Dry Density, $\gamma_{dMAX}$ (pcf)	Optimum Moisture Content, OMC(%)	Landform: Lakebed		
									Stratum: A	90%	95%
24	21	101	0.67	0.14	2.0	-	-	-	-	-	-
34	28	96	0.75	0.16	NONE	-	-	-	-	-	-
-	-	-	-	-	-	120	102	17	-	1.1	1.6
											2.1

\* Indicates the specimens were molded to the various percentages of the maximum dry density, using the impact or dynamic method of compaction.

SECTION 3

TYPICAL PROFILE NO. 3

Table E-4

## Data for Statistical Soil Classification

1. Northern Lake and Moraine Region  
 A. Calumet Lacustrine Plain

Typical Profile No. 3

Landform: Ground Moraine  
(Wisconsin)

	Ground Moraine (Wisconsin) - Stratum A						Classification	
	% Passing No. 200 Sieve	% Sand	% Silt	% Clay	Liquid Limit	Plasticity Index	Textural	AASHTO
Average Value								
Method 1 $\bar{X}_1$	81.0	19.0	53.4	27.6	31.4	15.3	Silty Clay Loam	A-6(10)
Method 2 $\bar{X}_2$	81.3	18.7	56.1	25.2	34.5	18.0	Silty Clay Loam	A-6(11)
Method 3 $\bar{X}_3$	82.5	17.5	56.6	25.9	33.0	16.7	Silty Clay Loam	A-6(11)
Standard Deviation								
Method 1 $S_1$	14.7	14.7	15.3	13.7	10.8	9.0		
Method 2 $S_2$	13.4	13.4	14.8	13.9	11.9	10.1		
Method 3 $S_3$	12.4	12.4	14.2	13.8	12.1	10.3		
Maximum Value, Max. $X_i$	99	60	91	58	59	39		
Minimum Value, Min. $X_i$	40	1	24	2	15	2		
Range R	59	59	67	56	44	37		



# I. NORTHERN LAKE AND MORaine REGION

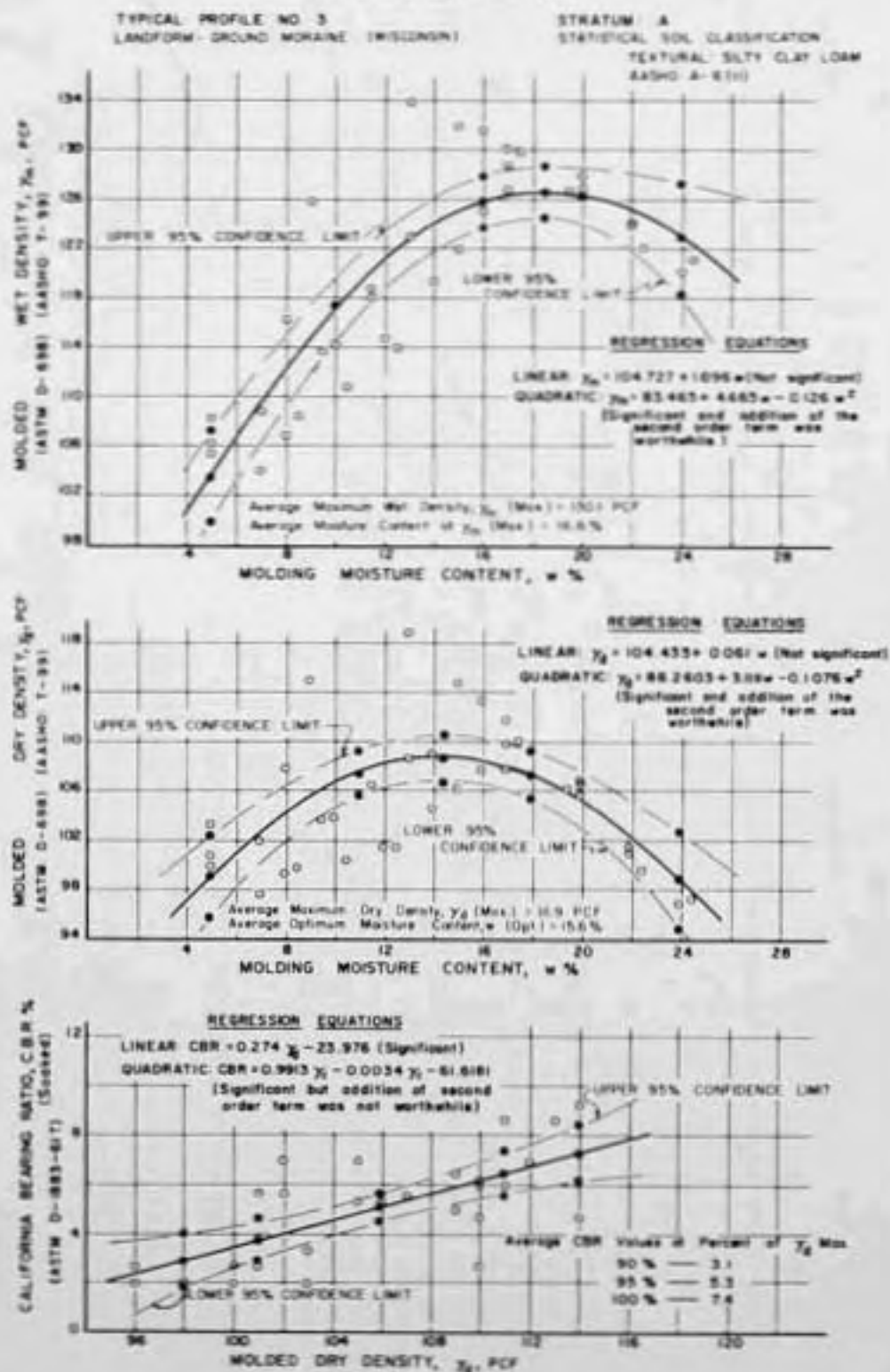
## A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 3 LANDFORM: GROUND MORaine (WISCONSIN)



FIGURE E-12

FIGURE E-13  
I. NORTHERN LAKE AND MORaine REGION  
A. CALUMET LACUSTRINE PLAIN



# I. NORTHERN LAKE AND MORaine REGION A. CALUMET LACustrine PLain

TYPICAL PROFILE NO. 3 STRATUM: A ORIGIN: GROUND MORaine (WISCONSIN)

STATISTICAL SOIL CLASSIFICATION- TEXTURAL: SILTY CLAY LOAM

AASHO: A-6(II)

## LIQUID LIMIT VS PLASTICITY INDEX RELATIONSHIP

PLASTICITY INDEX,  $I_p$  (%)

REGRESSION EQUATION:  $I_p = 0.825 w_L - 10.677$

CASAGRANDE'S LINE "A"

$I_p = 0.73 (w_L - 20 \%)$

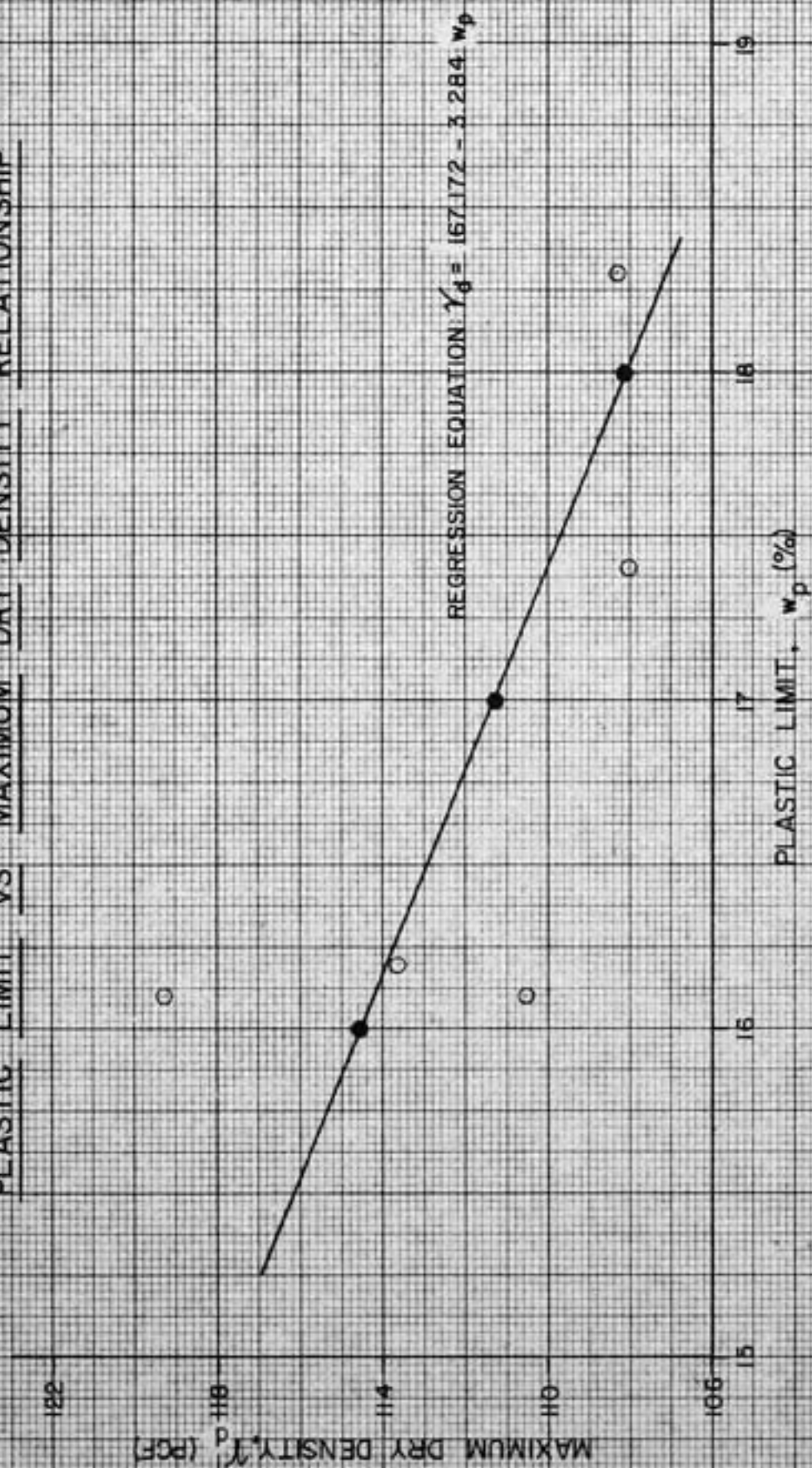
LIQUID LIMIT,  $w_L$  (%)

# NORTHERN LAKE AND MORaine REGION

## A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 3    STRATUM A    ORIGIN: GROUND MORaine (WISCONSIN)  
 STATISTICAL SOIL CLASSIFICATION -    TEXTURAL: SILTY CLAY LOAM    AASHO: A-6(11)

### PLASTIC LIMIT VS. MAXIMUM DRY DENSITY RELATIONSHIP





## NORTHERN LAKE AND MORaine REGION

## A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 3 STRATUM: A ORIGIN: GROUND MORaine ( WISCONSIN )

STATISTICAL SOIL CLASSIFICATION — TEXTURAL: SILTY CLAY LOAM AASHO: A-6 (II)

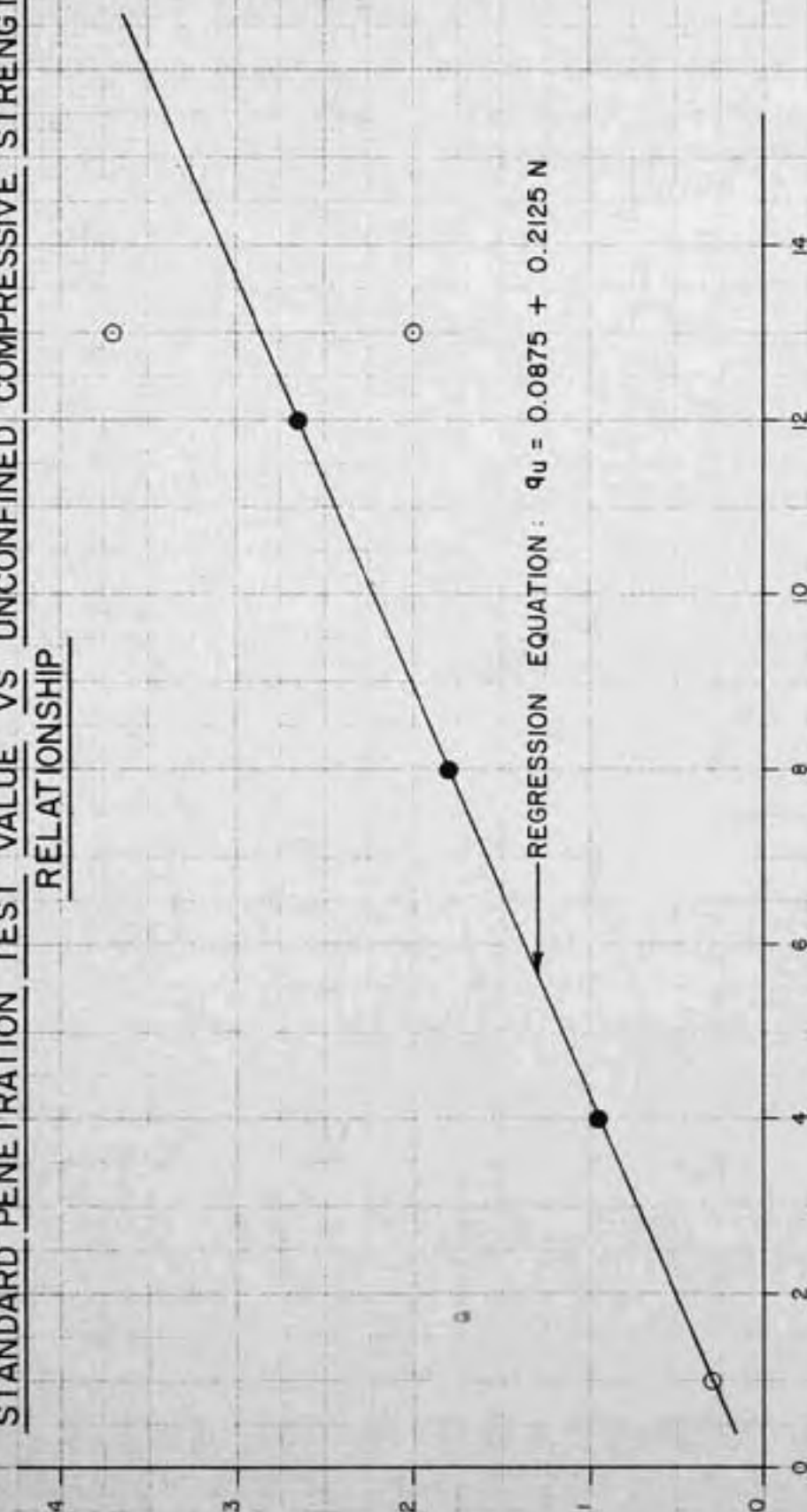
STANDARD PENETRATION TEST VALUE VS UNCONFINED COMPRESSIVE STRENGTH  
RELATIONSHIPUNCONFINED COMPRESSIVE STRENGTH,  $q_u$  (TSF)STANDARD PENETRATION TEST VALUE,  $N$  (BLOWS PER FOOT)REGRESSION EQUATION:  $q_u = 0.0875 + 0.2125 N$ 

FIGURE E-16



# NORTHERN LAKE AND MORaine REGION

## A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 3 STRATUM: A ORIGIN: GROUND MORaine (WISCONSIN)

STATISTICAL SOIL CLASSIFICATION -

TEXTURAL: SILTY CLAY LOAM

AASHTO: A-6 (11)

UNCONFINED COMPRESSIVE STRENGTH,  $q_u$  (TSF)

UNCONFINED COMPRESSIVE STRENGTH,  $q_u$  (TSF)

REGRESSION EQUATION:

$$\log q_u = 1.3471 - 0.0548w$$

NATURAL MOISTURE CONTENT VS LOG UNCONFINED  
COMPRESSIVE STRENGTH RELATIONSHIP

NATURAL MOISTURE CONTENT,  $w$  (%)

FIGURE NO. E-17

# I. NORTHERN LAKE AND MORaine REGION

## A. CALUMET LACUSTRINE PLAIN

TYPICAL PROFILE NO. 3 STRATUM: A ORIGIN: GROUND MORaine  
(WISCONSIN)

STATISTICAL SOIL CLASSIFICATION- TEXTURAL: SILTY CLAY LOAM

AASHO: A-6(II)

STANDARD PENETRATION TEST VALUE, N (BLOWS PER FOOT)

STANDARD PENETRATION TEST VALUE, N (BLOWS PER FOOT)

REGRESSION EQUATION:

$$\log N = 2.0966 - 0.0530 w$$

NATURAL MOISTURE CONTENT VS LOG STANDARD PENETRATION  
TEST VALUE RELATIONSHIP

NATURAL MOISTURE CONTENT,  $w$  (%)